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APRIL, 1932

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AMERICAN TELEPHONE & TELEGRAPH CO.
NEW YORK

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A Medium of Suggestion and a Record of Progress

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VOL. XI NO. 2

PUBLISHED QUARTERLY FOR THE BELL SYSTEM BY THE AMERICAN TELEPHONE AND TELEGRAPH COMPANY. SUBSCRIPTION, $1.50 PER YEAR, IN UNITED STATES AND CANADA; SINGLE COPIES, 50 CENTS

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A brief biographical note regarding Mr. Gherardi appeared in the list of contributors in the *Bell Telephone Quarterly* for January, 1931.

Lectures in the Lowell Institute by Bell System Representatives

ON January 5, 1932, a series of seven lectures by representatives of the Bell Telephone System was begun in the Lowell Institute, of Boston, Massachusetts, the general title of the series being "The Application of Science in Electrical Communication."

These lectures, in the order of their presentation, were as follows:

January 5—"An Introduction to Research in the Communication Field," by H. D. Arnold, Ph.D., Sc.D., Director of Research, Bell Telephone Laboratories.

January 8—"Research in Speech and Hearing," by Harvey Fletcher, Ph.D., Acoustical Research Director, Bell Telephone Laboratories.

January 12—"Transoceanic Radio Telephony," by Ralph Bown, Ph.D., Department of Development and Research, American Telephone and Telegraph Company.

January 15—"Picture Transmission and Television," by Herbert E. Ives, Ph.D., Sc.D., Electro-Optical Research Director, Bell Telephone Laboratories.

January 19—"Talking Motion Pictures and Other By-Products of Communication Research," by John E. Otterson, President, Electrical Research Products, Inc.

January 22—"Utilizing the Results of Fundamental Research in the Communication Field," by Frank B. Jewett, Ph.D., D.Sc., Vice President, American Telephone and Telegraph Company, President, Bell Telephone Laboratories.

January 26—"Social Aspects of Communication Development," by Arthur W. Page, A.B., Vice President, American Telephone and Telegraph Company.

Five of the seven lectures are published in this issue of the BELL TELEPHONE QUARTERLY, in the order of their presentation, with reproductions of most of the lantern-slides that were used as illustrations. It is unfortunately necessary to omit the second and fifth lecture in the series because they contain frequent references to illustrations and exhibits that cannot conveniently be reproduced.

EDITOR

An Introduction to Research in the Communication Field

A lecture delivered at the Lowell Institute, Boston, Massachusetts on January 5, 1932

TO have ideas and to share them—that makes civilization. Of course the ideas must be good ones if the civilization is to be worth while. Society recognizes this when it entrusts to Education the stupendous task of teaching us how to think and what to think about. But sharing is really the kernel of the matter. For civilization is not a solitary affair; no individual becomes civilized by and for himself alone. Civilization is a community affair and grows and spreads only as fast and as far as people can come to a common understanding. It is the business of communication to provide facilities to broaden and speed this concourse of thought and feeling. In any business it is the duty of research to carry forward its ideals and provide always better means of achieving them. Thus in communication, research seeks as its ultimate goal to break down the barriers of time, distance and expense which prevent the quick and easy meeting of our minds.

Perhaps you think this ideal too ambitious and far-reaching for practical folk to consider. We think not; for in idealism, in ambition and in practicality the modern research mind recognizes no limitations. This is especially true where a group is joined together in the common effort to understand and master all of some problem, from its deepest roots to its farthest branches. Just such an effort is joined in our research in communication. If at times we seem to go too deep or aim too high I would suggest that from the points to which we have ventured out we can perhaps see more clearly the value of what is in the depths and on the heights. We make no apology

for following where our vision leads, for after all that is Research.

In offering you an introduction to research in communication you can readily see I am attempting no simple task. The problems dealt with are numerous and complex. Fortunately, the succeeding lectures will bring to you a clearer insight of how some of these problems are handled in detail, how they materialize in useful forms, and why it is all worth while. For my part I shall try to give you a general idea of what we have to do, and how we go about doing it in this business of Research.

II

Let us consider first what it is that communication is called upon to accomplish. When I talk to you face to face you hear me and see me. These two processes are the most important in the communication of ideas; we have grown up with them from the childhood of the race; and we would like to feel that some time we shall be able at will and instantly to effectively project our ears and our eyes to any place in the world. We feel the need of a great deal more than the mere transportation of words. The mind is much too complex to find anything like complete expression in language. Our thoughts move too quickly and lose their full force before we can formulate them in speech or writing. But we must remember that after all words are rather recent acquisitions of the human race. We used our voices long before we had developed the rules of grammar, and even before we had much of a vocabulary. It is natural, therefore, that a great deal of the spontaneous contact between our minds has come to depend upon the intonations of our voices. We all know how completely the meaning of a sentence may be changed by the tone in which it is spoken. To be thoroughly satisfactory therefore a communication system must transport much more than mere words—it must transport the voice itself with all its shades of emotion and

personality. And ultimately it should transport vision as well. For the mind reveals itself through the expression of the face, the gleam of the eye, the motion of the body, as truly as through the voice. Indeed these modes of expression, which are so elementary and spontaneous, are often more clearly indicative of the mind than mere words can possibly be. The judge and jury always wish to see the witness and hear him speak; they are not content with a written record.

III

Now there is already in existence a communication system which, for very short distances, does all these desirable things, —the marvelous system that is within our own bodies. Nature solved tremendous problems in connecting our minds to the external world through our ears and eyes. Just how cunningly she used the materials and forces which she had at her disposal is becoming more apparent to us year by year. For example, consider what happens when we hear. We know that sound waves come through the air and shake the diaphragms of our ears in exact accordance with the motion of their source, whether that is the voice of a speaker or a musical instrument. Then comes about a marvelous transformation. The mechanical motion of our ear drum sets up a complicated train of mechanical and chemical changes and, as a result, up the nerves to the brain go a series of electrical pulses which carry every detail which previously existed in the motion of the air and the vibration of the ear drum. The earliest electrical telephone!

How do we know this is so? At Princeton University, Wever and Bray recently discovered that when they connected a vacuum tube amplifier and loud speaker directly to the nerves leading from the ear the loud speaker spoke out clearly the sounds which had been spoken directly into the ear. The result was just as if this apparatus had been connected to an

ordinary telephone line. Nature had anticipated us in transforming mechanical motion into electrical currents within the individual. She has left us, nevertheless, plenty of opportunity for hard work in extending the reach of electrical currents from person to person throughout the world.

Indeed, Nature has pointed us to many if not all the principles which we use in our art. Consider the voice. Signals from the brain, almost certainly electrical in character, control the motion of the air in our throats; and thus we have an amplifier and loud speaker system transforming tiny electrical currents into powerful air vibrations through the control of the muscular power which drives the lungs.

Consider the ether waves which we use in radio—we are not the first to use them for communication; Nature has also used them in providing us with sight. Wherever we turn we find clues which lead us on in our task of providing between individuals an extension of the communication facilities that Nature has already provided within the individual.

IV

We start then with these bare essentials: voice, ear and eye; air, electricity, and ether. To these are added the grosser material things out of which we must fabricate a satisfactory, economical and lasting communication system. Many of these constituents of our problem we must accept as we find them; but although we may not change them it is absolutely essential that we understand them. With other constituents we are allowed certain liberties; we can arrange them and to some extent modify them to meet our needs.

In the first category are, for example, the voice and the ear. If we are to face our task intelligently we must know exactly what the voice is and exactly how the ear responds. Without these facts we cannot hope to find the ultimate solutions of our problems. The last twenty years have seen a rapid ad-

vance in our knowledge of these things, but nevertheless there still remains a vast deal that we do not know and a large and basic part of our research concerns itself with these matters.

In this same category we find air waves, ether waves, and electricity. The nature and behavior of these we cannot modify, but to use them to best advantage we must thoroughly comprehend them. Air waves seem comparatively simple and understandable, yet there is still a great deal to learn even about these elementary things upon which all of acoustics rests. Ether waves are obviously more perplexing subjects of research. Perhaps there is no ether, then of course there are no ether waves. Nevertheless, ether or no ether there is no doubt about the usefulness of light and of radio waves, and whether or not we can completely comprehend what they are we must at any rate bend every effort to understand all the rules which must be followed in using them, and all the difficulties with which their use is surrounded. We must not only know how to start ether waves and how to detect them, we must find out how they behave when they have left our control and are projected into a space filled with static, with ionization, with Heaviside layers, with cosmic rays, and whatever else the sun, moon, stars, and weather may provide.

And then, still in this category of things which we must accept as they are, we find electricity. There is perhaps nothing simpler in the world than electricity, for we have come to think that it is the aggregation of little units which are always the same and quite unchangeable. Yet in the process of arriving at this conclusion we have found astounding new uses for electricity. So long as we thought of it as a fluid with electromagnetic properties we could indeed make marvelous use of it, but when we fully realized its unit structure, we found a magic way opening to new uses in our present day multitudinous electron tubes. And now electricity is taking on new allure. We have found that despite its simple unit structure it somehow succeeds in behaving like a wave motion.

The proof of this fact came about, strangely enough, in our laboratory where we were trying to understand electricity in order to use it better for communication purposes. In what way this knowledge will affect the communication art we can hardly hope to see at this time. Nevertheless, the importance of the knowledge cannot be doubted, and its discovery is just another demonstration that there is still much to be found out about these elementary things which we cannot change but must use. With regard to all these we conceive it our job to thoroughly understand what Nature has provided in order that we may make no mistakes and miss no opportunities in utilizing them.

V

It is in the second category, however, comprising the things which Nature permits us to modify that we find the majority of our research problems. These may be divided roughly into two classes; problems of composition and characteristic, and problems of shape and association.

Compositions and characteristics are the prime concerns of the chemistry and physics of materials. The possibilities of studies and improvements along these lines are practically boundless. Even those properties of materials which relate directly to the communication industry present almost unlimited ground for research.

As a striking example, consider the effect of composition on magnetic properties. Iron is the outstanding magnetic element. For many purposes ordinary commercial iron is sufficiently good. But in transforming the delicately modulated electrical currents that represent speech in our communication systems we need materials far more sensitive and uniform in their response to magnetic forces. These we have found by compounding iron with nickel, with cobalt, with molybdenum. And the end is not yet, for every year we are finding new compositions and new treatments that give us constantly better magnetic properties.

Consider also the combinations of the elements barium and strontium which make possible the truly astounding life and efficiency of our vacuum tubes; of sodium and potassium and caesium and other elements which have so increased the usefulness of photoelectric cells. Or consider the new organic compounds which are constantly giving us better dielectrics, better insulators, greater strength in our materials and more complete protection against wear and weather. Nor is the scope of our research in this broad field of chemistry and physics limited to discovering the characteristics of new compounds; it must also include studies of how to make them available with uniformly good quality and at reasonable cost.

But it is in the problems of shape and association of the materials which we have at our disposal that we find the most complicated and the most immediately important of all our tasks. The telephone transmitter, for instance, is composed of some thirty different parts. The test of the adequacy of this assemblage of parts is that it must take from the air the minute and highly complicated energy flow that is speech and must translate this into a flow of electricity which retains all the voice's complexity; and it must do this reliably and cheaply, under all vicissitudes of location and climate, and throughout a long period of years. Its design is mathematically exact in an unusual sense of the words. Our fundamental studies of the voice have made it possible for us to describe the air-borne form of words in terms of Fourier's analysis—a mathematical description of wave form in terms of frequency, amplitude and phase—with very great accuracy and completeness. We also have developed methods for analyzing the electrical currents which flow out from the transmitter and can describe them in the same mathematical terms. And so we may think of the transmitter as transforming the mathematical equation which, in terms of mass, elasticity and viscosity, represents the motion of the air, into the corresponding equation which in terms of inductance, capacity and resistance represents the motion of

electricity in the telephone wire. It is just because this whole problem has been considered as a mathematical one, and every detail of the transformation traced through all the parts of the instrument that we have our present day quality of telephone, phonograph, and sound picture reproduction. The promise for the future rests in the extension of just such exact mathematical analysis to every problem in which there is a translation of energy between mechanical and electrical forms.

While the transfer of energy from one embodiment to another without loss of detail presents one of the most difficult of all our problems in the construction of apparatus there are almost as great difficulties found in associating transformers, condensers and resistances to transmit and preserve the detail of the electric currents themselves in their transit through the communication system. These, too, call for the use of very difficult mathematics in their solution. Indeed, we frequently find that the flow of electricity through complex apparatus presents mathematical puzzles which we cannot solve at all. Nevertheless, it is a source of great satisfaction to be able to engineer in a rigorous mathematical way so many problems whose analogues in other arts must still be handled by cut and try methods. One of the most important aims of our research is to extend this firm mathematical foundation under all the complicated structure of our design and manufacture.

VI

But perhaps the most fascinating of all our problems are those which deal with the rejuvenation of speech currents as they travel along through the communication system. We may be as mathematically exact as we please in transforming sound waves into corresponding electrical currents and yet fail completely in reaching our final objective unless we have some way to restore the energy that is being constantly lost as the currents go along the wires. And yet we must do that very

thing not merely once, but scores and even hundreds of times in long distance connections. The delicate pattern of the voice which is contained in the current has to be repaired and restored by the addition of new energy much as a child patches up a snow man as it slowly melts away.

Suppose we ask how much of the original energy can be left in speech that has gone from San Francisco to London. The figures are truly startling, and are more difficult to comprehend than the astronomical magnitudes scientists are now talking so much about. You may remember that the latest estimates put the number of separate particles in the universe at about ten to the seventy-ninth power. That means the difficulty of finding one particular electron in the whole universe is measured by some such enormous number as the digit one with seventy-nine ciphers after it. But a very simple calculation shows that the difficulty of finding a bit of the original energy in the voice current delivered in London is at least one-with-a-hundred-ciphers-after-it times greater than the difficulty of finding one particular electron in the universe. It is because we have mastered this problem of amplifying voice currents that the telephone has stretched out during the past few years from a reach of a few hundred miles to cover the whole world. And this problem of amplication is still a vital and growing one, in which research promises greater accomplishments in the future.

In addition to amplification some curious tricks are resorted to in transporting voice currents. Of course, speech must pass in both directions during a telephone connection, but sometimes it is very desirable that it shall not be moving in both directions at the same time. We, therefore, use electrically operated gates which close the lines to traffic in one direction while it is allowed to proceed in the other. Now the gate must open just before the speech arrives, for if it does not open ahead of time the initial syllable of the oncoming speech will collide with it and be damaged beyond recognition, or lost

completely. Perhaps you have driven an automobile on a road protected by signals operated by the car itself. While still at a distance from a crossroad your car actuates an electric circuit which causes the signal light to stop cross traffic and so allows you to proceed. This is relatively simple of accomplishment, for the electric current flies on ahead of your car and there is plenty of time for the signal to operate. But when we try to set stop-go signs for voice currents we are confronted with the fact that there is no way of sending a signal on ahead at a speed greater than that of the voice current itself. So, of course, we must in some way hold back the voice currents until the necessary switches can operate. The idea is simple, but the method of its accomplishment is not so obviously simple. What we frequently do is to send the voice current into an electrical labyrinth which is so artfully designed that the current finds its way through it slowly and yet suffers no ill effect in the process.

Delay and storage devices for speech offer a vast field for research. Some must delay speech for only a thousandth part of a second and others must store it indefinitely. Some must reproduce the speech only once and then present a clean page for the next record, while others must reproduce the speech thousands of times without noticeable change in quality. The methods employed are as varied as the problems themselves and may be electrical, magnetic, optical, or mechanical as circumstances demand. It is in the proper association of all these ways and means of dealing with the energy and form of voice and music that some of the most important advances of recent years have been made, and there is still a wide field of research and exploration awaiting us.

There are also, as you can well imagine, vast complications involved in the electrical signalling and switching which makes it possible to establish telephone connection between person and person. When, for example, you use a dial instrument the motion of the dial establishes electric currents which in

turn cause mechanical parts in the central office to move with more than human accuracy and send out electric signals to call the distant person with whom you wish to speak. But this is not all. There are conditions under which it is necessary that the numbers which you indicate with the dial be actually spoken in the central office, and this also has become possible by ingenious combinations of electrical, mechanical and optical parts. Problems such as these are obviously not to be solved by mathematics—they call for a rare type of ingenuity, a mind undaunted by detail and having at its disposal the latest and best of all that research can offer.

But I must not attempt to mention the thousands of researches which have been accomplished, are in progress, or loom ahead of us. Ours is a live and growing art; and research ventures out wherever new growth starts or is demanded. I trust, however, that I have mentioned enough fields of endeavor to indicate how numerous must be the separate streams of research which flow together to stimulate the new growth within the wide domain of communication. And it is most important that they do really flow together and not trickle along separately. For individual effort can not well face problems as complicated as these. It is only by co-ordinated effort that progress can be assured.

VII

Now that we have in mind the ultimate object of our researches, the nature of the problems with which we have to deal, and the materials and forces which we have at our disposal, let us consider briefly how we go about our work. It is very fortunate for me that you have all grown so familiar with research men, their problems and their methods through the lectures of the many brilliant scientists who have in person presented their work to you under the aegis of this Institute. I shall assume your full acquaintanceship with the individual

of the genus researcher, and go straight on to some general considerations which underlie our own peculiar problem of conducting researches in an organized way, with an eye toward their usefulness in the art of communication.

But although I must not stop to dwell at any length on the problems of the individual research worker, we must not for a moment forget that research is in its very essence individualistic; for only by keeping this constantly in mind can we understand and evaluate its conduct, its results and its significance.

Nor must we let ourselves fall into the very common confusion which fails to distinguish clearly between research itself and the tools which it uses. Research is of the mind and not of the hands, a concentration of thought and not a process of experimentation. We all know too well the common picture of the research worker—a microscope, a retort, a balance, a measure and a man in an apron. It depicts, it is true, something of the delicacy of the apparatus required and suggests the skill and patience necessary for its manipulation. It fails, however, to represent research itself, which is as apt in the use of crude apparatus as of delicate apparatus; whose special pride, indeed, is to bend the simplest tools to new uses, and whose real interest is not in the skill of the performer but in the meaning of the performance.

Research is not constructing and manipulating; it is not observing and accumulating data; it is not merely investigating or experimenting; it is not "getting the facts"; although each of these activities may have an indispensable part to play in it. Research is the effort of the mind to comprehend relationships which no one has previously known. And in its finest exemplifications it is practical as well as theoretical; trending always toward worthwhile relationships; demanding common sense as well as uncommon ability.

VIII

I think we can get most quickly to a common understanding of research as we meet it in the field of communication if I tell you about one particular problem and what had to be done to solve it. It has to do with the amplification of speech and music by vacuum tubes—a process you are all familiar with in your own radio sets and by which, with the mere turning of a dial, you can proceed at will from the almost inaudible to the all too audible. It has to do, also, in a very practical way, with the cost factors that must underlie the engineering of all long distance communication systems.

Let us approach this particular problem as some of us may have approached our arithmetic problems in school—by first looking in the back of the book for the answer. And this is the way the answer reads: "If when you try to transmit speech over wires you permit the speech current to become smaller than a certain definite size no amplifier can ever restore it to understandable form."

Now this is a fact of obvious and exceedingly great importance; for, as we have already learned in our consideration of the enormous amplification necessary in a transcontinental and transoceanic conversation, once speech currents have been started along their way the farther they go the smaller they become. We can revive them with amplifiers, but it is expensive and sometimes almost impossible to install these at frequent intervals along all our routes. We can also construct our system so that the currents die away less rapidly, but only at a cost which soon becomes prohibitive. What we would like to do would be to allow the currents to go long distances and become very small indeed before we amplify them. Indeed, this is just what we must do in long undersea cables where we can only maintain amplifiers at the terminals. But Nature holds up her hand and says "Stop! You must not go below my ordained minimum current." And so we have the

necessary size and cost and ultimate practicability of such a system sharply determined by this fundamental rule which we cannot change and must respect. It is a bench mark from which we must learn to survey our whole scheme of speech transmission engineering.

Why is there any such limit to the size of usable current? The answer is very simple and you will all see it and understand it as quickly as I mention it. You know that in any piece of wire the atoms are always in motion and that it is this motion which determines the temperature of the wire. You also know that electricity in a conductor shares this heat motion and because it does there is a continual surging about of the electricity in the wire. Now this is just what happens when speech is going along a wire, except that the surgings of electricity which are controlled by speech are of an orderly sort and conform to the pattern of the voice, whereas the always present surgings of electricity due to temperature are quite irregular in pattern. Obviously if the speech currents get smaller and smaller they will finally be over-ridden by the random motions of electricity and become so mixed up with them that they never can be extricated in intelligible form. Consider your own radio sets. You know that if there is a thunderstorm and consequently very bad static, and in your effort to hear you keep adding more and more amplification, you really do not improve the situation at all; everything becomes louder, the static as well as the program. That is the way it is if ever you let speech currents become so small that they are obscured by the irregular heat motion of electricity;—the static within the wire.

IX

Now that we know and understand the answer let us go back and imagine ourselves trying to solve this problem and thus we shall learn something of the research processes in-

volved. The very first difficulty that confronts us is that we are not aware there is any such problem. Of course, *you* see the problem plainly enough, but only because I have told you about it. Someone had to see it first and recognize it without any prompting. I want to emphasize that the type of mind which first sees such problems is indispensable to research. Hundreds of people knew that electricity partakes of the heat motion in metals but it never occurred to them that the fact might be of practical everyday significance. The problem was born when, in a mind that understood all these things, there first flashed out the conscious question "Can the random motion of electricity be of such a nature and so big that it is of tangible importance?"

After we have come to recognize the problem we must next attempt to evaluate it. This requires a mind that is critical rather than creative. It must, of course, be constructively critical, for it must not squelch a good new idea at its very start, and yet it must be keenly and coldly critical for it must not let us go on and waste time and money in following a line of unsound thought. It must above all be a closely reasoning mind and equipped with the tools of logic, which in engineering means equipped with the machinery of mathematics. There must be brought to bear all the available knowledge of physics, chemistry and mathematics; whatever additional information is needed must be clearly indicated; and thus we come to the point where experimentation must begin.

When we find that new facts are required to evaluate a problem, as was the case in this matter of the noise of electricity, a still different side of the research mind must be brought into play, a side which is closely in step with Nature herself. It knows how to meet actual material things on their own grounds and cope with them. It knows all about instruments and their limitations. It knows the places to be bold and the places to be cautious in experimentation. It is linked with the experimental touch—something which can

never be got entirely by training but which can never find itself properly in any field except through long experience in that field. It must know, for instance, in this particular problem, all the technique, the possibilities and the pitfalls, in carrying amplification to the limit, and measuring and establishing in the face of great experimental difficulties the actual magnitudes of these tiny electrical motions.

Finally we find ourselves confronted with the very practical question—"What does it matter, now that you know all about it?" You and I could never answer this question in any satisfactory manner. We would have to know how large a vagrant current may be and still not mutilate speech—and this is a large research in itself. We would have to know how much it means in cost and trouble to keep speech currents from becoming too small. We would have to know what particular parts of our circuits are most susceptible to this trouble. We would have to know what palliative measures are possible and at what cost. We would have to emerge gradually and imperceptibly from research into the more stabilized field of engineering.

X

I chose this particular problem for discussion because it illustrates the many sidedness of the approach to a research problem and the variety in the mental attitude and training which must be brought to bear. First of all we must have the questing spirit—the mind that fastens to the solid ground of established fact with a grasp so firm that it holds securely while reaching out for unknown and untried positions, and yet so lightly that it swings on unhampered and unrestrained as soon as the new footing is found. This mind must be bold, curious, unbelieving, iconoclastic; perhaps not too scornful of our present accepted beliefs yet always eager for a different and better view. Sure but light in its tread, it is always on

treacherous ground but never lets itself be unbalanced into an abyss.

Then we must have the analytical mind to survey the new ground as it is won. This is far more a believing mind. It sums up the knowledge and beliefs of the past and will not budge from its established ground until firmly convinced there is real advantage in doing so.

And at the last we must have the mind of the husbandman that moves into the new territory with all the skill and machinery of research and engineering, and checks and measures and cultivates all the new grounds' possibilities.

These are the three requirements; the spirit to adventure, the wit to question, and the wisdom to accept and use. Few men can lay claim to those three in any superlative degree, but any successful research man must have all to some degree; and he must bring them all to bear on each new problem which he undertakes.

Now the essence of organized research as we visualize it is to give a greater freedom, a surer ground, a wider field, a more constructive expression to these types of mind. We do not seek just to assemble a group of similarly inclined minds and let them function individually. We try by linking hands to support the adventurer so he can reach further and more securely. We try to turn upon new ground a sharper scrutiny by a varied group than would be possible by any individual, and we try to bring to the cultivation of new ground the skill, the technique, the experimental genius of a large group of enthusiastic husbandmen. And yet we do not try to have a group of questers, a group of criticizers and a group of experimenters. We try rather to multiply and to some extent steady the stream of achievement by using these different attributes of all the researchers' minds as though they were one large mind. An ideal difficult, perhaps impossible, to achieve in more than limited measure, and yet, if achieved to any degree, fraught with untold possibilities.

XI

The story of research in communication is a tale of literally thousands of problems and thousands of men. It is too big to be told in its entirety—certainly I would not dare attempt it. But an introduction, after all, is just an invitation and an opportunity to become acquainted. That is all I have pretended to offer; that, and a glimpse of the unifying spirit that holds work and men all together in one strong drive toward the common goal of our research.

H. D. ARNOLD

Transoceanic Radiotelephony

A lecture delivered at the Lowell Institute, Boston, Massachusetts, on January 12, 1932

IN 1915 speech was first sent experimentally across the Atlantic Ocean by radiotelephony. Today there are 30 transoceanic radiotelephone circuits in operation transporting an international commerce of speech. It is my purpose to trace briefly some of the technical considerations underlying this novel communication development.

Although the first successful experiments were made in 1915 and following the war came further tests and demonstrations, it was not until 1927 that the first commercial system was opened to traffic between New York and London. The next year brought a second circuit on this New York–London route and two circuits between Europe and South America. The map, Fig. 1, shows in solid lines the lace work of international telephone circuits which exists today and with dotted lines the additional circuits in prospect. These invisible speech highways extend the scope of telephone service so that a United States subscriber may now be connected with about 33,000,000 other telephones in the world which constitute 91 per cent of the world's telephones.

The value of these circuits lies in their ability to tie together the existing continental wire networks into a world telephone network. Thus, one of the first problems was to accomplish effectively the junction of space transmission and wire transmission of speech.

Interconnecting Wire and Radio Systems

More clearly to comprehend the nature of this problem let us examine the diagram shown in Fig. 2. This is a diagram

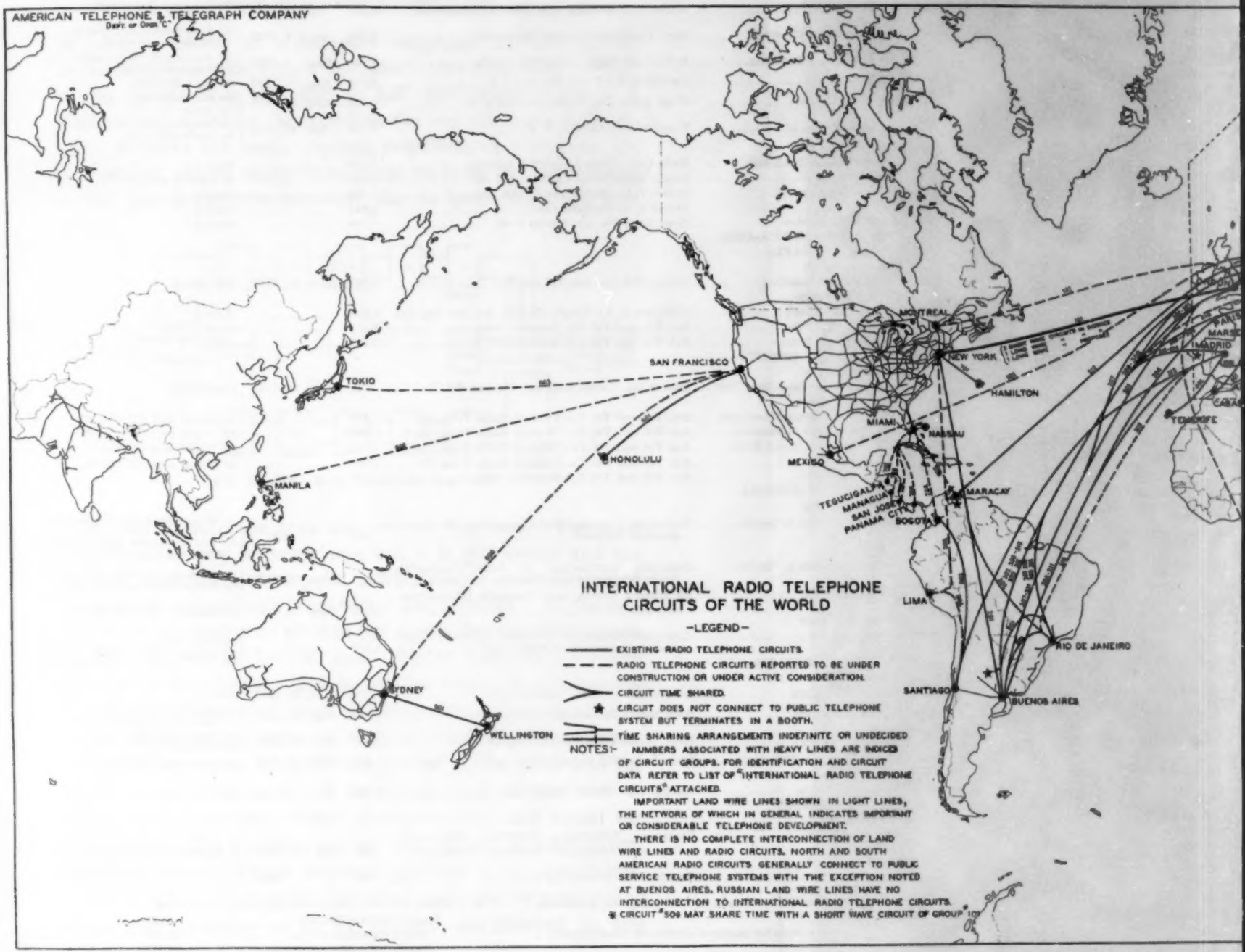
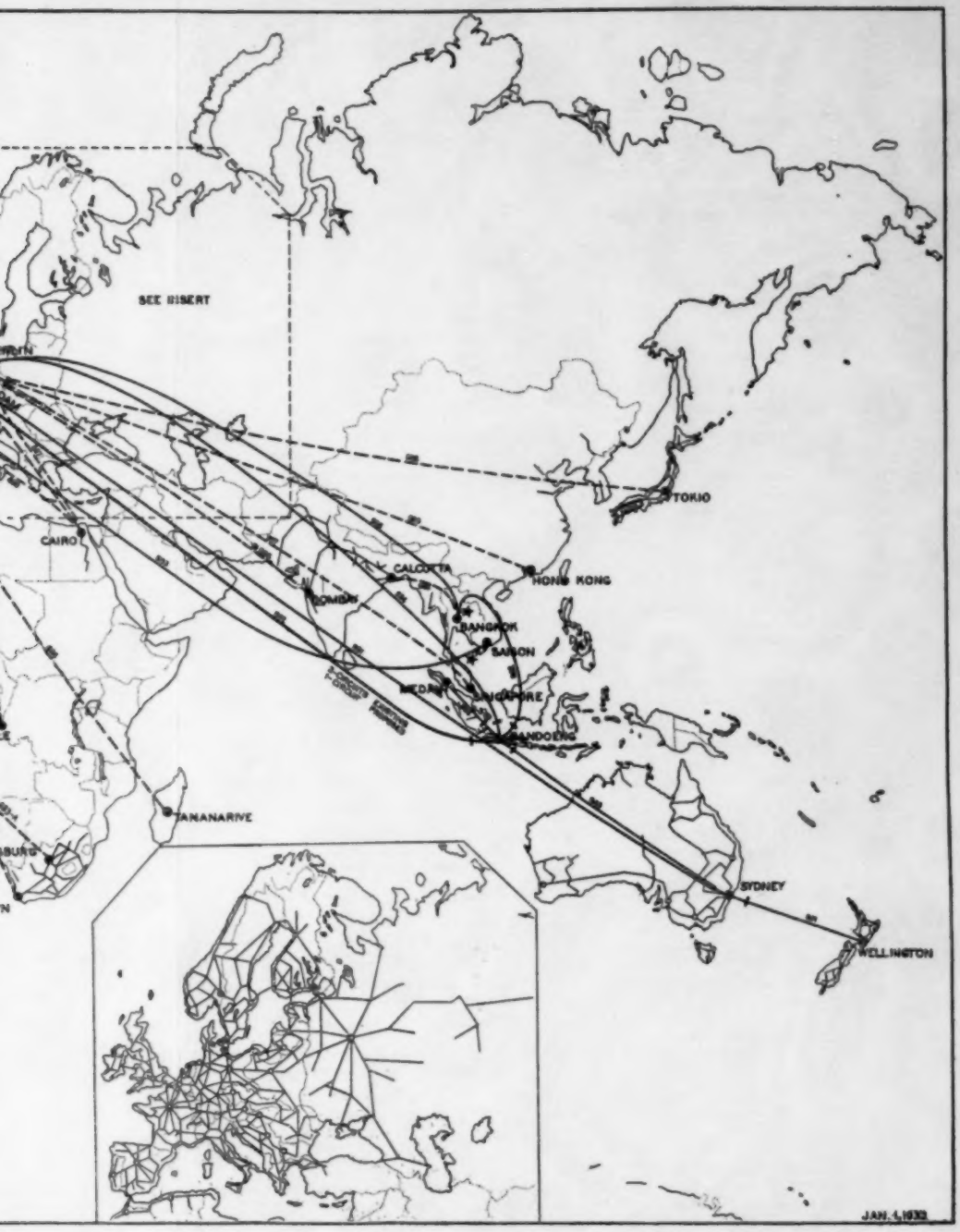

AMERICAN TELEPHONE & TELEGRAPH COMPANY
Dept. of Oper. "C"
INTERNATIONAL RADIO TELEPHONE CIRCUITS OF THE WORLD
-LEGEND-
EXISTING RADIO TELEPHONE CIRCUITS.
RADIO TELEPHONE CIRCUITS REPORTED TO BE UNDER CONSTRUCTION OR UNDER ACTIVE CONSIDERATION.
CIRCUIT TIME SHARED.
CIRCUIT DOES NOT CONNECT TO PUBLIC TELEPHONE SYSTEM BUT TERMINATES IN A BOOTH.
TIME SHARING ARRANGEMENTS INDEFINITE OR UNDECIDED
NOTES:-
NUMBERS ASSOCIATED WITH HEAVY LINES ARE INDICES OF CIRCUIT GROUPS. FOR IDENTIFICATION AND CIRCUIT DATA REFER TO LIST OF "INTERNATIONAL RADIO TELEPHONE CIRCUITS" ATTACHED.
IMPORTANT LAND WIRE LINES SHOWN IN LIGHT LINES, THE NETWORK OF WHICH IN GENERAL INDICATES IMPORTANT OR CONSIDERABLE TELEPHONE DEVELOPMENT.
THERE IS NO COMPLETE INTERCONNECTION OF LAND WIRE LINES AND RADIO CIRCUITS. NORTH AND SOUTH AMERICAN RADIO CIRCUITS GENERALLY CONNECT TO PUBLIC SERVICE TELEPHONE SYSTEMS WITH THE EXCEPTION NOTED AT BUENOS AIRES. RUSSIAN LAND WIRE LINES HAVE NO INTERCONNECTION TO INTERNATIONAL RADIO TELEPHONE CIRCUITS.
* CIRCUIT #509 MAY SHARE TIME WITH A SHORT WAVE CIRCUIT OF GROUP 109
SAN FRANCISCO
TOKIO
HONOLULU
MANILA
SYDNEY
WELLINGTON
MONTREAL
NEW YORK
HAMILTON
MIAMI
NASSAU
MEXICO
TEGUCIGALPA
MANAGUA
SAN JOSE
PANAMA CITY
BOGOTA
MARACAY
LIMA
RIO DE JANEIRO
SANTIAGO
BUENOS AIRES
MADRID
TENERIFE

FIG. 1. INTERNATIONAL RADIO TELEPHONE CIRCUITS OF THE WORLD AS OF JA

THIS MAP, PREPARED BY DEPARTMENT OF OPERATION C, AMERICAN TELEPHONE AND TELEGRAPH COMPANY, SHOWS ON EACH CIRCUIT LINE AN IDENTIFICATION NUMBER

FIG. 1. INTERNATIONAL RADIO TELEPHONE CIRCUITS OF THE WORLD AS OF JANUARY 1, 1932.

GRAPH COMPANY, SHOWS ON EACH CIRCUIT LINE AN IDENTIFICATION NUMBER. MORE DETAILED IN



1932.

Detailed Information is Tabulated by Identification Numbers on the Back of this Map.

Circuit Group Index No.	Circuit Terminals	Ownership
	NORTH AMERICA-EUROPE	
	Existing Circuits	
101.	(1) London-New York (Long Wave)	British P. O.-Am. Tel. and Te
	(2) London-New York	British P. O.-Am. Tel. and Te
	(3) London-New York	British P. O.-Am. Tel. and Te
	(4) London-New York	British P. O.-Am. Tel. and Te
	Proposed Circuits	
101.	(5) London-New York (Long Wave)	British P. O.-Am. Tel. and Te
102.	London-Montreal	British P. O.-Canadian Marco
103.	Berlin-Mexico City	German P. O.-Mexican Govt.
	NORTH AMERICA-SOUTH AMERICA	
	Existing Circuits	
201.	Buenos Aires-New York	Compania Internacional de Tel. Co.
202.	New York-Rio de Janeiro	Am. Tel. and Tel. Co.-Com nacional do Brasil*
	Proposed Circuits	
203.	Lima-New York	Compania Peruana de Telef Tel. and Tel. Co.
204.	Bogota-Miami	Compania Telefonica Central-
205.	Maracay-Miami	Compania Annonima Nacion zuela-Am. Tel. and Tel. Co
	EUROPE-SOUTH AMERICA	
	Existing Circuits	
301.	Buenos Aires-London	Compania Internacional de R
302.	Buenos Aires-London	Transradio Internacional-Brit
303.	London-Rio de Janeiro	British P. O.-Companhia R sileira
304.	Buenos Aires-Paris	Compania Internacional de R
305.	Buenos Aires-Paris	Transradio Internacional-Cie
306.	Paris-Rio de Janeiro	Cie Gle de T.S.F.-Compan Brasileira
307.	Berlin-Buenos Aires	German P. O.-Compania Int
308.	Berlin-Buenos Aires	German P. O.-Transradio Int
309.	Berlin-Rio de Janeiro	German P. O.-Companhia R sileira
310.	Berlin-Maracay, (Venezuela)	German P. O.-Venezuelan Ge
311.	Buenos Aires-Madrid	Compania Internacional Telephonica Nationale d'E
312.	Buenos Aires-Madrid	Transradio Internacional-C Espanola
313.	Madrid-Santiago	Compagna Telephonica N Compania Internacional de
314.	Madrid-Rio de Janeiro	Compania Transradio Espan telegraphica Brasileira
	Proposed Circuits	
315.	Madrid-Rio de Janeiro	Compagna Telephonica N Companhia Radio Interna
316.	Brussels-Buenos Aires	Belgium Govt.-Transradio I
	EUROPE-AFRICA	
	Existing Circuits	
401.	Casablanca-Paris	Moroccan Tel. & Tel. Admi
402.	Madrid-Teneriffe	Compagna Telephonica N Compagna Telephonica N
	Proposed Circuits	
401.	Casablanca-Paris	Moroccan Tel. & Tel. Admi
403.	Capetown-London	Overseas Com. Co. of So. Af
403A.	Johannesburg-London	South African P. O.-British
404.	Cairo-London	Marconi Radio Tel. of Egyp
405.	(1) Algiers-Paris	French P.T.T.-French P.T.T
	(2) Algiers-Paris	French P.T.T.-French P.T.T
406.	Brussels-Leopoldville	Belgium Govt.-Belgium Gov
407.	Berlin-Cairo	German P.O.-Marconi Radi
408.	Paris-Tananarive (Madagascar)	French P.T.T.-French P.T.T
409.	Cairo-Paris	Marconi Radio Tel. of Egyp

Ownership	Distance Statute Miles	Service Date	Time Sharing Arrangements
m. Tel. and Tel. Co.	3,448	Jan. 7, 1927	Not shared.
m. Tel. and Tel. Co.	3,448	June 6, 1928	Not shared.
m. Tel. and Tel. Co.	3,448	June 1, 1929	Not shared.
m. Tel. and Tel. Co.	3,448	Dec. 1, 1929	Not shared.
m. Tel. and Tel. Co.	3,448	1934	Not shared.
Canadian Marconi Ltd.	3,245	1932	At London with 404.
Mexican Govt.	6,034	.....	Note 3.
ernacional de Radio*-Am. Tel. and	5,327	Apr. 3, 1930	At New York with 202.
Tel. Co.-Companhia Radio Inter-Brasil*	4,849	Dec. 18, 1931	At New York with 201. At Rio de Janeiro with 315-802.
uana de Telefonos, Limitada*-Am. Co.	3,679	.....	Note 3.
efonica Central-Am. Tel. and Tel. Co.	1,514	.....	Note 3.
nonima Nacional Telefonos de Vene-el. and Tel. Co.	1,362	.....	Note 3.
ernacional de Radio*-British P. O.	6,921	Dec. 12, 1930	At Buenos Aires with 307-802. At London with 302-303.
ternacional-British P. O.	6,921	Dec. 12, 1930	At Buenos Aires with 305-308-312-316-801. At London with 301-303.
-Companhia Radiotelegraphica Bra-	5,769	May 21, 1931	At London with 301-302. At Rio de Janeiro with 306-309-314-801.
ernacional de Radio*-Cie Gle de T.S.F.	6,868	June 11, 1930	At Buenos Aires with 311. At Paris with 305-306.
ternacional-Cie Gle de T.S.F.	6,868	Feb. 1, 1929	At Buenos Aires with 302-308-312-316-801. At Paris with 304-306.
T.S.F.-Companhia Radiotelegraphica	5,695	Mar. 31, 1930	At Paris with 304-305. At Rio de Janeiro with 303-309-314-801.
-Compania Internacional de Radio*	7,406	Sept. 10, 1930	At Berlin with 308-309. At Buenos Aires with 301-802.
-Transradio Internacional	7,406	Dec. 10, 1928	At Berlin with 307-309. At Buenos Aires with 302-305-312-316-801.
.-Companhia Radiotelegraphica Bra-	6,230	Mar. 21, 1930	At Berlin with 307-308. At Rio de Janeiro with 303-306-314-801.
-Venezuelan Govt.	5,150	Sept. 13, 1931	Not shared.
nternacional de Radio*-Compagna Nationale d'Espagna*	6,248	Oct. 12, 1929	At Buenos Aires with 304. At Madrid with 313-315.
Internacional-Compania Transradio	6,248	1929	At Buenos Aires with 302-305-308-316-801. At Madrid with 314.
Telephonica Nationale d'Espagna*-nternacional de Radio S.A.*	6,645	Apr. 17, 1931	At Madrid with 311-315. At Santiago with 803-804.
ansradio Espanola-Companhia Radio-Brasileira	5,057	1930	At Madrid with 312. At Rio de Janeiro with 303-306-309-801.
Telephonica Nationale d'Espagna*-Radio Internacional do Brasil*	5,057	Jan. 1932	At Madrid with 311-313. At Rio de Janeiro with 202-802.
.-Transradio Internacional	7,028	Feb. 1932	At Brussels with 406. At Buenos Aires with 302-305-308-312-801.
. & Tel. Admin.-Cie Gle de T.S.F.	1,132	Nov. 3, 1930	At Paris with 503.
Telephonica Nationale d'Espagna*-Telephonica Nationale d'Espagna*	1,128	Jan. 22, 1931	At Madrid with 1,001.
. & Tel. Admin.—French P.T.T.	1,132	.....	Not shared.
. Co. of So. Africa-British P.O.	6,011	Feb. 1, 1932	At London with 301-302-303.
P. O.-British P. O.	5,637	.....	Note 3.
o Tel. of Egypt-British P. O.	2,179	1932	At London with 102.
.-French P.T.T.	836	1932	Not shared.
.-French P.T.T.	836	1932	Not shared.
.-Belgium Govt.	3,893	Apr. 1932	At Brussels with 316.
-Marconi Radio Tel. of Egypt	1,805	.....	Note 3.
.-French P.T.T.	5,448	.....	Note 3.
o Tel. of Egypt-French P.T.T.	1,993	.....	Note 3.

Circuit Group Index No.	Circuit Term
	EUROPE-ASIA-O
	Existing Circuits
501.	London-Sydney
502.	(1) Amsterdam-Bando
	(2) Amsterdam-Bando
503.	Paris-Saigon
504.	Bandoeng-Berlin
505.	Bangkok-Berlin
	Proposed Circuits
502.	(3) Amsterdam-Bando
506.	Bombay-London
507.	London-Singapore
508.	London-Tokio
509.	Hong Kong-London
	NORTH AMERIC
	OCEANIA
	Existing Circuits
601.	Honolulu-San Francis
	Proposed Circuits
602.	Manila-San Francisco
603.	San Francisco-Tokio
604.	San Francisco-Sydney
	NORTH AME
	Existing Circuits
701.	Hamilton (Bermuda)-
	Proposed Circuits
702.	Miami-Tegucigalpa (
703.	Miami-Managua (Nic
704.	Miami-San Jose (Cos
705.	Miami-Panama
706.	Miami-Nassau
	SOUTH AME
	Existing Circuits
801.	Buenos Aires-Rio de
802.	Buenos Aires-Rio de
803.	Bogota-Santiago
	Proposed Circuits
804.	Lima-Santiago
	ASIA-OCEA
	Existing Circuits
901.	Sydney-Wellington
902.	Bandoeng-Bangkok
903.	Bandoeng-Sydney
904.	Bandoeng-Medan (Su
	Proposed Circuits
905.	Bangkok-Calcutta
	EUROP
	Existing Circuits
1,001.	Madrid-Mallorca
	Proposed Circuits
1,002.	Calvi-Marseilles

NOTES: 1. *Indicates I

2. Service dat

3. Definite inf

4. At Bandoe
1 transm
1 transm
1 transm
1 transm
1 transm

ice e	Time Sharing Arrangements
1927	Not shared.
1928	Not shared.
1929	Not shared.
1929	Not shared.
1934	Not shared.
1932	At London with 404.
....	Note 3.
1930	At New York with 202.
1931	At New York with 201. At Rio de Janeiro with 315-802.
....	Note 3.
....	Note 3.
....	Note 3.
1930	At Buenos Aires with 307-802. At London with 302-303.
1930	At Buenos Aires with 305-308-312-316-801. At London with 301-303.
1931	At London with 301-302. At Rio de Janeiro with 306-309-314-801.
1930	At Buenos Aires with 311. At Paris with 305-306.
1929	At Buenos Aires with 302-308-312-316-801. At Paris with 304-306.
1930	At Paris with 304-305. At Rio de Janeiro with 303-309-314-801.
1930	At Berlin with 308-309. At Buenos Aires with 301-802.
1928	At Berlin with 307-309. At Buenos Aires with 302-305-312-316-801.
1930	At Berlin with 307-308. At Rio de Janeiro with 303-306-314-801.
1931	Not shared.
1929	At Buenos Aires with 304. At Madrid with 313-315.
1929	At Buenos Aires with 302-305-308-316-801. At Madrid with 314.
1931	At Madrid with 311-315. At Santiago with 803-804.
1930	At Madrid with 312. At Rio de Janeiro with 303-306-309-801.
1932	At Madrid with 311-313. At Rio de Janeiro with 202-802.
1932	At Brussels with 406. At Buenos Aires with 302-305-308-312-801.
1930	At Paris with 503.
1931	At Madrid with 1,001.
...	Not shared.
1932	At London with 301-302-303.
...	Note 3.
1932	At London with 102.
1932	Not shared.
1932	Not shared.
1932	At Brussels with 316.
..	Note 3.
..	Note 3.
..	Note 3.

Circuit Group Index No.	Circuit Terminals	Ownership	Distance Statute Miles	Service Date	Time Sharing Arrangements
	EUROPE-ASIA-OCEANIA				
	Existing Circuits				
501.	London-Sydney	British P. O.-Amalgamated Wireless Australasia	10,557	Apr. 30, 1930	At London—Not shared. At Sydney—Note 3.
502.	(1) Amsterdam-Bandoeng	Neth. Govt.-Neth. Indies Tel. Admin.	7,294	Jan. 8, 1929	At Amsterdam—Not shared. At Bandoeng—Note 4.
	(2) Amsterdam-Bandoeng	Neth. Govt.-Neth. Indies Tel. Admin.	7,294	Dec. 1, 1929	At Amsterdam—Not shared. At Bandoeng—Note 4.
503.	Paris-Saigon	Cie Gle de T.S.F.-Cie Gle de T.S.F.	6,298	Apr. 11, 1930	At Paris with 401.
504.	Bandoeng-Berlin	Neth. Indies Tel. Admin.-German P. O.	6,726	Dec. 29, 1929	At Bandoeng—Note 4. At Berlin with 505.
505.	Bangkok-Berlin	Siamese Govt.-German P. O.	5,349	Apr. 15, 1931	At Bangkok—Note 3. At Berlin with 504.
	Proposed Circuits				
502.	(3) Amsterdam-Bandoeng	Neth. Govt.-Neth. Indies Tel. Admin.	7,294	.....	Note 3.
506.	Bombay-London	Indian Radio Teleg. Co.-British P. O.	4,545	.....	At London with 101(4).
507.	London-Singapore	British P. O.-Imp. & Int. Comm. Ltd.	7,694	.....	Note 3.
508.	London-Tokio	British P. O.-Japanese Govt.	5,941	.....	Note 3.
509.	Hong Kong-London	Hong Kong Tel. Co.-British P. O.	5,979	.....	Note 3.
	NORTH AMERICA-ASIA-OCEANIA				
	Existing Circuits				
601.	Honolulu-San Francisco	Mutual Tel. Co.-Am. Tel. and Tel. Co.	2,393	Dec. 23, 1931	Not shared.
	Proposed Circuits				
602.	Manila-San Francisco	Philippine L. D. Teleph. Co.-Am. Tel. and Tel. Co.	6,969	.....	Note 3.
603.	San Francisco-Tokio	Am. Tel. and Tel. Co.-Japanese Govt.	5,133	.....	Note 3.
604.	San Francisco-Sydney	Am. Tel. and Tel. Co.-Australian P. O.	7,425	.....	Note 3.
	NORTH AMERICA				
	Existing Circuits				
701.	Hamilton (Bermuda)-New York	Imp. & Int. Comm. Ltd.-Am. Tel. and Tel. Co.	795	Dec. 21, 1931	Not shared.
	Proposed Circuits				
702.	Miami-Tegucigalpa (Honduras)	Am. Tel. and Tel. Co.-Tropical Radio Teleg. Co.	919	.....	At Miami with 703-704-705.
703.	Miami-Managua (Nicaragua)	Am. Tel. and Tel. Co.-Tropical Radio Teleg. Co.	1,002	.....	At Miami with 702-704-705.
704.	Miami-San Jose (Costa Rica)	Am. Tel. and Tel. Co.-Tropical Radio Teleg. Co.	1,120	.....	At Miami with 702-703-705.
705.	Miami-Panama	Am. Tel. and Tel. Co.-Tropical Radio Teleg. Co.	1,161	.....	At Miami with 702-703-704.
706.	Miami-Nassau	Am. Tel. and Tel. Co.-Bahamas Govt.	175	.....	.....
	SOUTH AMERICA				
	Existing Circuits				
801.	Buenos Aires-Rio de Janeiro	Transradio Internacional-Companhia Radiotelegraphica Brasileira	1,227	1931	At Buenos Aires with 302-305-308-312-316. At Rio de Janeiro with 303-306-309-314.
802.	Buenos Aires-Rio de Janeiro	Compania Internacional de Radio*-Companhia Radio Internacional do Brasil*	1,227	Dec. 12, 1931	At Buenos Aires with 301-307. At Rio de Janeiro with 202-315.
803.	Bogota-Santiago	All America Cables, Inc.*-Compania Internacional de Radio S.A.*	2,644	Aug. 1, 1931	At Santiago with 313-804.
	Proposed Circuits				
804.	Lima-Santiago	Compania Peruana de Telefonos, Limitada*-Compania Internacional de Radio S.A.*	1,537	.....	At Lima—Note 3. At Santiago with 313-803.
	ASIA-OCEANIA				
	Existing Circuits				
901.	Sydney-Wellington	Australian P. O.-New Zealand Govt.	1,375	Nov. 25, 1930	Note 3.
902.	Bandoeng-Bangkok	Neth. Indies Tel. Admin.-Siamese Govt.	1,469	Apr. 15, 1931	At Bandoeng—Note 4. At Bangkok—Note 3.
903.	Bandoeng-Sydney	Neth. Indies Tel. Admin.-Australian P. O.	3,392	Dec. 23, 1930	At Bandoeng—Note 4. At Sydney—Note 3.
904.	Bandoeng-Medan (Sumatra)	Neth. Indies Tel. Admin.-Neth. Indies Tel. Admin.	875	Sept. 16, 1931	At Bandoeng—Note 4.
	Proposed Circuits				
905.	Bangkok-Calcutta	Siamese Govt.-Indian Radio Co.	1,008	.....	Note 3.
	EUROPE				
	Existing Circuits				
1,001.	Madrid-Mallorca	Compagna Telephonica Nationale d'Espagna*-Compagna Telephonica Nationale d'Espagna*	330	Oct. 24, 1931	At Madrid with 402.
	Proposed Circuits				
1,002.	Calvi-Marseilles	French P.T.T.-French P.T.T.	185	1932	Note 3.

NOTES: 1. *Indicates Int. Tel. and Tel. Co. subsidiary or affiliate.

2. Service dates for proposed circuits are those planned.

3. Definite information not available.

4. At Bandoeng there are 5 transmitters:
   1 transmitter operates with 502-504-903-904
   1 transmitter operates with 502-504-902
   1 transmitter operates with 502-504-903
   1 transmitter operates with 502-504
   1 transmitter operates with 903

5. The circuit group index system employed is as follows:

Intercontinental Circuits—	Index
North American-Europe	100-199
North America-South America	200-299
Europe-South America	300-399
Europe-Africa	400-499
Europe-Asia-Oceania	500-599
North America-Asia-Oceania	600-699
Intracontinental Circuits—	
North America	700-799
South America	800-899
Asia-Oceania	900-999
Europe	1,000-1,099
Africa	1,100-1,199

of what is known as a four-wire telephone toll circuit. It is called a four-wire circuit because in the long-haul portion of the circuit from toll office to toll office separate one-way paths are provided for the speech in the two directions and two pairs of wires are used. Speech amplifiers or telephone repeaters are placed along these paths to bring up the volume of the speech currents whenever, due to losses, they fall to a

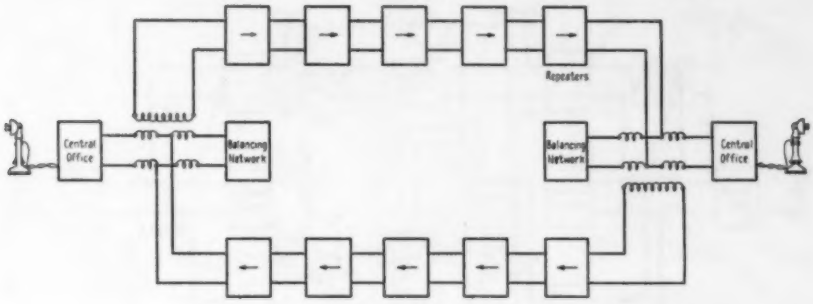


FIG. 2. FOUR-WIRE TELEPHONE CIRCUIT.

value too close to the noise currents on the lines. The total amplification may be very large but it is *distributed* and the speech currents are at no point much stronger or much weaker than at the subscriber's transmitter and receiver. At the terminals of this four-wire portion are shown three-winding transformers known as hybrid coils. These function after the manner of Wheatstone bridges and by virtue of the balance between the two-wire connected line and an artificial line called the balancing network, tend to prevent speech currents from getting across from the output end of one path into the input of the other path. It is evident that if this were to occur, speech currents would circulate round and round the two paths. The balances are not perfect and to some extent this does occur. Those wayward portions of the speech currents, which go back to the talker or make one or more round trips before passing on to the listener, are delayed by this

detour and sometimes sound like echoes, which indeed is what they are called by the telephone engineer. But the wire system is comparatively stable and by simple devices and adjustments, these echoes can be kept from causing trouble.

The diagram of Fig. 3 has been set up to show a simple radiotelephone link in such a way as to make apparent its similarity to the four-wire type of wire telephone circuit. The

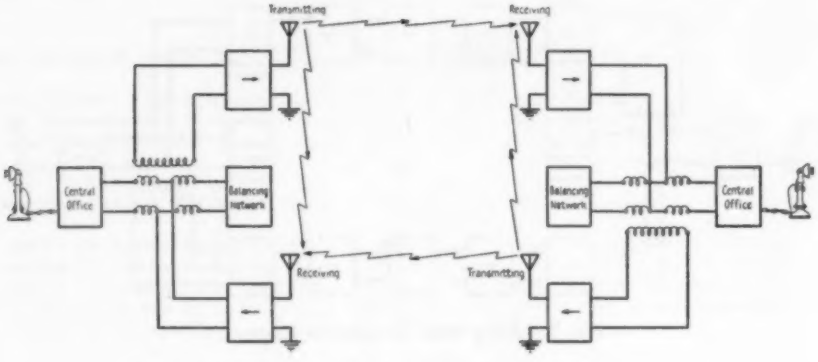


FIG. 3. SIMPLE FORM OF RADIOTELEPHONE CIRCUIT.

differences also become apparent. The amplification is all *lumped* at the terminals of the two paths rather than distributed along them. At each end is a powerful radio transmitter and a sensitive radio receiver.

The transmitter is a tremendous amplifier sending out the voice in the form of radio waves with a power so great that its equivalent in sound might be pictured as a chorus of all the people in the United States assembled in a multitude and speaking in unison.

The receiver is far more sensitive than the human ear. It "hears" radio waves equivalent in power to the voice of a single man several miles away in free air.

Thus, it is evident that even though the transmitter and receiver are many miles apart and operating on different radio

channels, the crossfire from the former into the latter may be very severe.

For this and other reasons, it is necessary to provide some means of shutting off the receiver when the transmitter is sending out by the speaker's voice and correspondingly shutting off access to the transmitter when the receiver is active. The telephone subscriber cannot do this but we can make his

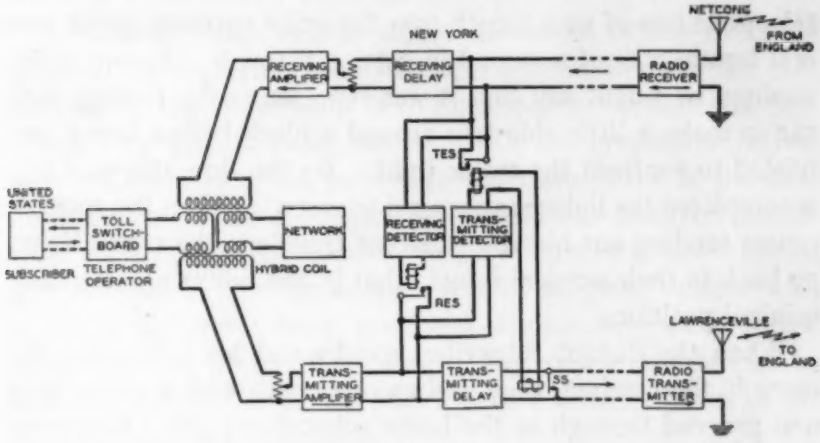


FIG. 4. VOICE-OPERATED SWITCHING SYSTEM FOR RADIOTELEPHONE TERMINALS.

voice do it for him through the agency of automatic switches operated by the telephone currents which his voice generates.

Fig. 4 gives a schematic diagram of the United States end of one of the transatlantic circuits showing the essential features of such a voice-operated device. The functioning of the apparatus illustrated is briefly as follows: The relay TES is normally open so that received signals pass through freely to the subscriber. The relay SS is normally closed to short-circuit the transmitting line. Speaking in terms of automobile traffic signals, it is as if the transmitting line showed a red light and the receiving line a green one. When the United States subscriber speaks and his voice currents come speeding down the line toward the transmitter, they pass the transmitting de-

tector which, like an automatic traffic control, recognizes their presence and acts to open the short circuit at TES, or turn the light to green. Simultaneously the relay SS is closed to short-circuit the receiving line, placing its traffic signal at red. It takes time to accomplish these functions and it is necessary to prevent the speech currents from getting into trouble by passing the red light before it has a chance to change. The delay circuit does this. Electrically the delay circuit is an artificial telephone line of such length that the voice currents spend several hundredths of a second in getting through. In our traffic analogy we might say that it was represented by forcing each car to make a little side trip around a block before being permitted to confront the traffic light. By the time this side trip is completed the light has changed to green. When the speaker ceases sending out his voice current travelers, the traffic lights go back to their original colors; that is, the relays assume their original positions.

When the distant subscriber speaks and his voice currents come in the receiver, they find an open path with a green light and proceed through to the home subscriber's ear. However, there is provided an automatic protection in the receiving detector and delay circuit, which, acting in conjunction with the relay RES, disables the transmitting detector so that stray noise currents, or incoming speech currents which get across the hybrid coil and start toward the transmitter, cannot act to change the state of affairs until the distant speaker has finished.

All these actions which it takes some minutes to describe occur so fast that the subscribers are able to converse back and forth without being conscious that there is anything unusual about the system.

A device of this kind so completely cuts away from the two one-way radio circuits the limitations which would otherwise be imposed by the junction with the wires that they become effectively independent systems which are simply called

upon to transport speech between the terminal stations with a minimum of distortion and noise interference. Except that these one-way circuits must be co-ordinated in some degree to avoid excessive interaction, they may be designed as separate systems and we may consider but one of them in developing further the purely radio aspects of the entire circuit.

Radio Links

A one-way radio system across the ocean differs from the familiar broadcasting type of radio system in that the sole purpose of the transmitter is to reach one particular and generally very distant radio receiver with the greatest effectiveness. Evidently great power at the transmitter is the first desideratum. The developments which have occurred in vacuum tube construction, based largely upon the invention of a technique of sealing copper vessels to glass vessels with vacuum tightness, have produced high-power water-cooled tubes capable of handling almost any power which can be economically justified. In Fig. 7 such a tube is shown in the hands of the two engineers.

To broadcast power in all directions would be wasteful. Directive antenna systems for converging the radiated waves into a beam aimed at the distant receiver have been studied intensively and are applied in modern point-to-point radio systems. Many types have been evolved. Two, used for short-wave transoceanic telephony are shown in Figs. 5 and 6. These two types are roughly of equal effectiveness. They serve to illustrate the advances made in the past two years. The lofty steel towers hung with great wire curtains are replaced by a few telephone poles carrying a conductor around the four sides of a diamond.

At the distant end the receiver has problems all its own. The most important of these is radio static noise. Thunder storms are going on continuously somewhere on the earth.

Each lightning flash sends a powerful electromagnetic disturbance radiating round the world, which produces a crackle in every radio receiver it passes. It has been estimated that the sum total of these flashes is equivalent to the continuous operation of a one million-kilowatt radio transmitter, certainly a potent source of interference. Refined tuning of the receiver can eliminate the interfering signals from radio stations on other channels, but the impulsive character of static disturbances defies attempt to eliminate them completely by any tuning process. Fortunately these disturbances come from many directions, while the desired signals come from but one direction, the direction of the transmitting station. A directive receiving antenna system which responds freely to waves coming from that one direction and is deaf in all other directions goes far to mitigate the effect of atmospherics. Antennas of the diamond type similar to that shown in Fig. 6 are being employed in new receiving installations.

To summarize this discussion of the radio stations, we may say that (1) at the transmitting end there should be as much power as the cost will permit justifying and it should be radiated efficiently and as far as possible only toward the receiving station, and (2) at the receiving end the system should employ refined selective tuning or filtering circuits and it should receive as little as possible from other directions than the direction of the transmitter. Let us now examine some of the other ways in which these desirable things have been accomplished and some further problems and refinements.

Long-Wave System

The first commercial transatlantic radiotelephone circuit operated (and still operates) on long waves at 5000 meters (or 60 kilocycles). In addition to employing a power amplifier of nearly 200 kilowatts capacity comprising the battery of water-cooled tubes shown in Fig. 7 it employs a method of

FIG. 6. HORIZONTAL DIAMOND TYPE ANTENNA CONNECTED FOR TRANSMITTING.

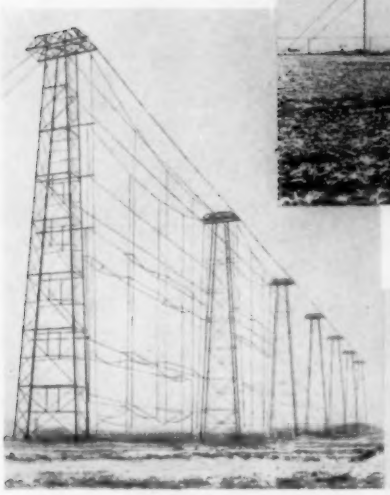


FIG. 5. SHORT-WAVE DIRECTIVE TRANSMITTING ANTENNAS AT LAWRENCEVILLE, NEW JERSEY.

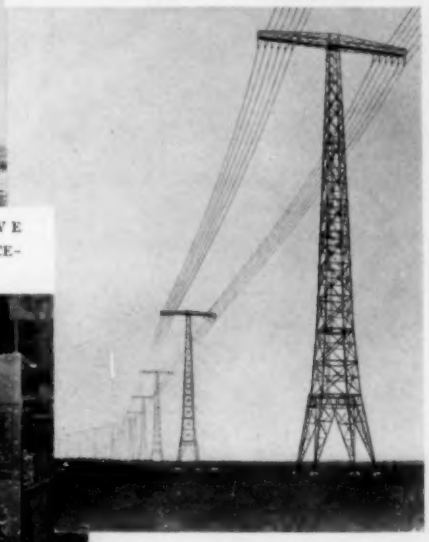


FIG. 8. LONG-WAVE TRANSMITTING ANTENNA AT ROCKY POINT, LONG ISLAND.

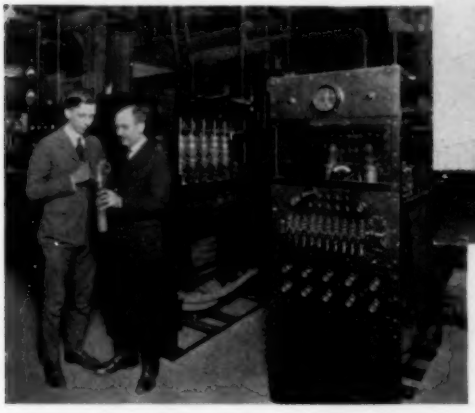


FIG. 7. LONG-WAVE HIGH POWER AMPLIFIER AT ROCKY POINT, LONG ISLAND.

FIG. 9. RECEIVING WAVE ANTENNA AT HOULTON, MAINE.

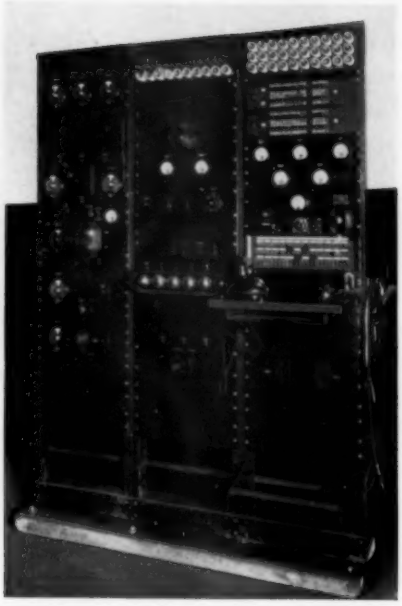


FIG. 12. SHORT-WAVE TRANSOCEANIC TELEPHONE RECEIVER.

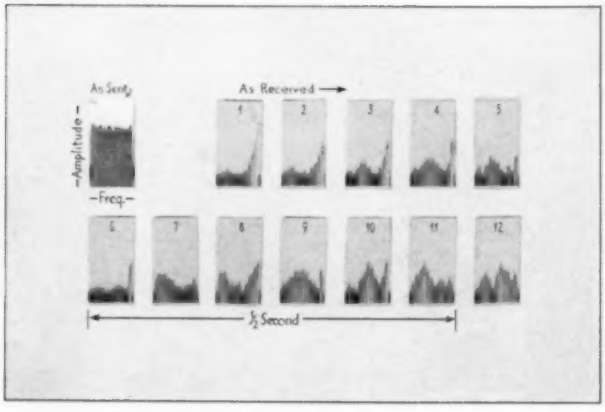


FIG. 13. OSCILLOGRAPHIC RECORDS OF SHORT-WAVE SELECTIVE FADING TESTS.

transmission unique in radio, giving a power effectiveness several times as great as the ordinary method. In the usual method used in broadcasting and for short-wave systems, there is transmitted continuously a constant carrier wave which carries no intelligence but is necessary to permit a simple detecting apparatus for receiving. There are also two bands of frequencies resulting from modulation, called sidebands, one just above the carrier frequency and one just below it. Each of these sidebands carries the message in full. The single-sideband-carrier-eliminated method of telephone transmission, originally developed for wire carrier telephony and now applied to long-wave radio, lops off one sideband and the carrier and transmits the remaining sideband only. This permits the full power capacity of the transmitter to be brought to bear on this one message carrying component. At the receiving end the eliminated carrier frequency is resupplied from a small oscillator in the receiving set.

In the original long-wave system a non-directive transmitting antenna is employed. Fig. 8 shows a picture of this antenna at Rocky Point, Long Island. In the new additional long-wave system now being designed there will be a directive transmitting antenna adapted from the so-called wave antenna used in long-wave receiving.

The wave antenna is simply a pair of wires several miles long carried on telephone poles in a straight line toward the correspondent station, and grounded at the ends through suitable terminating circuits. Fig. 9 shows one of them in use at the transatlantic receiving station at Houlton, Maine. To increase the directivity for receiving, several of these antennas are placed side by side separated some distance apart. They are connected to the receiving set through transmission lines.

Since thunder storms predominate in the warmer portions of the globe, it might be expected that the more northern latitudes would be freer from static. Putting the receiving station in Maine combines this advantage with the further one

that this location places most of the static sources to the rear of the directive system where their effectiveness in producing interference in the receiver is much reduced.

This long-wave circuit has been described because it illustrates the problems met in the pioneer work on transoceanic radiotelephony and because it illustrates further the basic problems common to all point-to-point radio circuits. But it is not likely that any considerable number of them will ever be built. In spite of the fact that the single sideband method of transmission narrows the frequency channel occupied by such a system and that further economy of frequency space has been achieved in the existing system by operating both the eastbound and westbound channels in the same frequency band, the total frequency space available for long-wave long distance use is too limited to accommodate more than a few circuits. The diagram in Fig. 10 shows how limited this frequency space is.

Short-Wave Systems

The discovery that short waves of the order of 15 to 50 meters could be sent long distances made it evident that further expansion should be sought in the short-wave range.

The short-wave range (also shown in Fig. 10) is vastly wider in kilocycles but, nevertheless, has its limitations as to the number of communication facilities it affords. For a given route of a few thousand miles a single frequency gives good transmission for only a part of the day. As shown in Fig. 11, for example, from the United States to Europe a frequency in the neighborhood of 18,000 to 21,000 kilocycles (17 to 14 meters) is good during daylight on the Atlantic. But in the dusk period a frequency of about 14,000 kilocycles (22 meters) is better. For the dark hours something like 9000 kilocycles (33 meters) gives best transmission. For midnight in winter an even lower frequency near 6000 kilocycles (50 meters) is

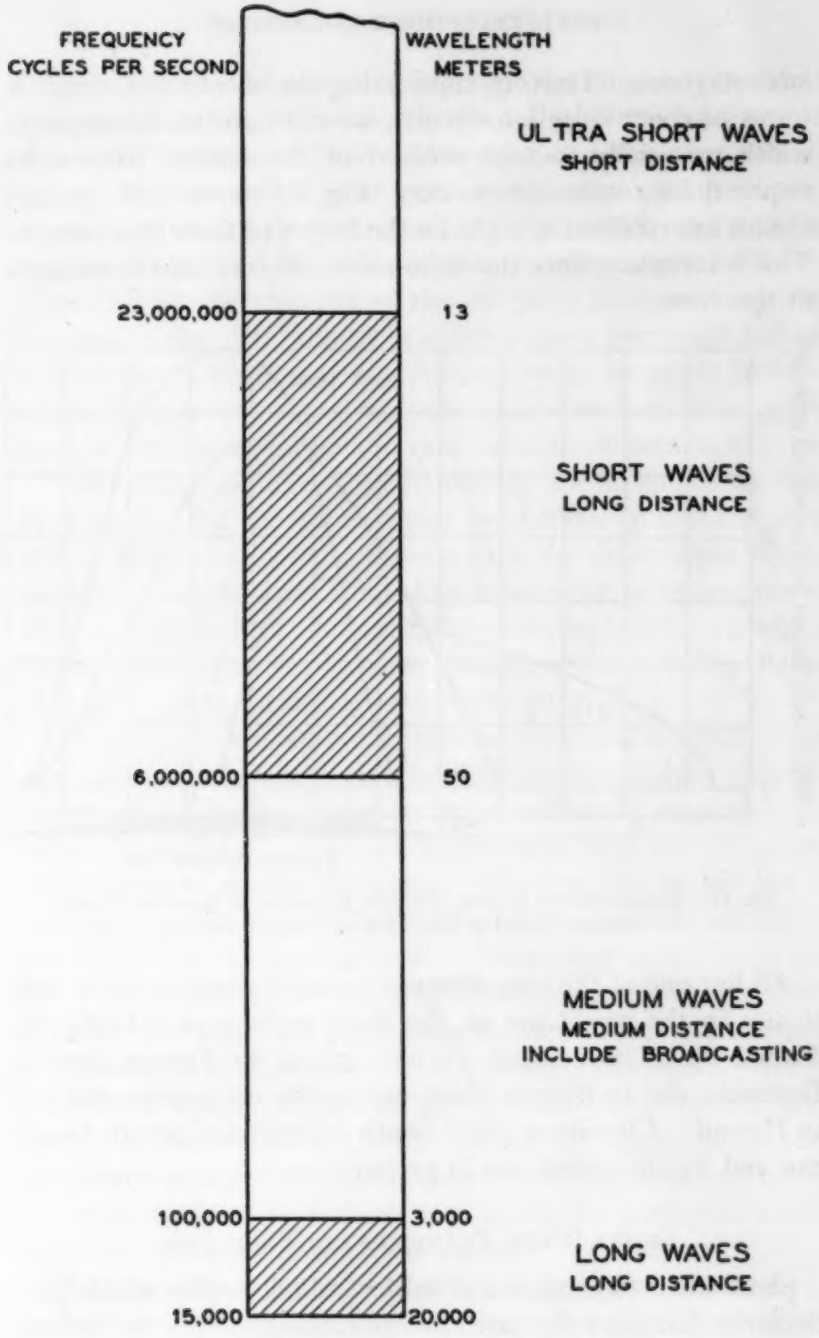


FIG. 10. RADIO FREQUENCY SPECTRUM.

advantageous. Thus, in considering the short-wave range in terms of communication circuits, we must shrink its apparent width materially to take account of the several frequencies required for continuous service. Fig. 11 shows that stronger signals are received at night on the longer of these short waves. This is fortunate since the radio noise also increases in strength at this time.

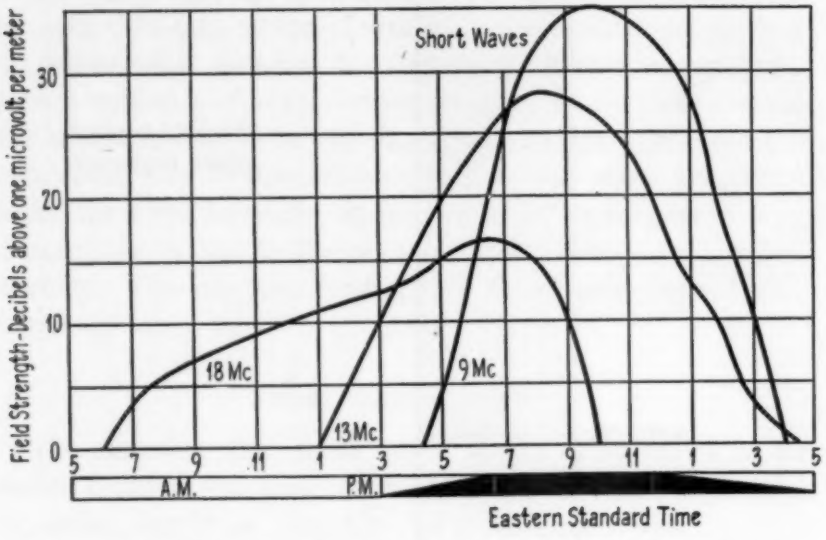


FIG. 11. REPRESENTATIVE CURVES SHOWING STRENGTH OF RECEIVED SIGNALS AGAINST TIME OF DAY. (MC.—MEGACYCLES.)

All but one of the long distance radiotelephone systems now in use in the world are of the short-wave type. From the United States three such circuits extend to Europe, one to Bermuda, one to Buenos Aires, one to Rio de Janeiro and one to Hawaii. Circuits to other South American, Central American and Pacific points are in preparation.

SHORT-WAVE TRANSMISSION PROBLEMS

Short-wave transmission is subject to one frailty which particularly hampers its use for telephony. This is fading.

Where fading is of the ordinary type familiar to broadcast listeners, consisting of waxing and waning of the loudness of the entire transmitted band of frequencies, a device called an automatic gain control is of value and is employed at the receiving station in the transoceanic telephone circuits. With this device the amplification in the receiver is automatically controlled by the strength of the incoming carrier wave. As the carrier strength falls the amplification is increased and as it rises the amplification is decreased so as to result in substantially constant signal output. A commercial short-wave receiver employing automatic gain control is shown in Fig. 12.

The fading problem is unfortunately not so simple as this. It is rarely that the entire signal band fades in and out as a unit. More usually certain parts of it are down while others are up. That is to say the fading is selective as to frequency. This is perhaps best illustrated by referring to Fig. 13 which shows a variety of the changes through which a fading signal may go. (*Figs. 12 and 13 are facing page 105.*)

These figures are oscillographic records of a test signal. The test signal consists of twelve tone frequencies spaced through a part of the audio-frequency range ordinarily employed for voice transmission. Each of the vertical lines on the record corresponds to one of the tones. The first line on the left is 425 cycles, having a pitch about midway between middle C and high C in the musical scale. Proceeding to the right the tones are spaced at 170-cycle intervals up to the last at 2295 cycles. The tones are all put into the circuit together in equal amplitude, as indicated by the upper left-hand figure. When they have been transmitted through the radio circuit they come out much modified. The remaining figures taken consecutively, as numbered, show the curious shapes through which the record passed in a short time under the particular conditions for which the record was made.

It is possible to set up experimentally, in the laboratory, a cathode ray oscillograph in such a way that this characteristic

is delineated continuously on the screen of the tube. The characteristic is seen to be constantly in motion, passing through strange configurations.

When these tones are listened to at the transmitting end by means of a telephone receiver the sound is a sort of chord of definite and steady musical character. Listened to at the receiver after they have been transmitted over a short-wave transoceanic circuit when selective fading is present, the changes in tonal character, as the maxima and minima of the fading characteristic wander through the band, are clearly distinguishable. When speech or music is being transmitted the effect of selective fading is noticed as a distortion of the quality.

Defects in short-wave transmission due to radio noise and fading with its consequent distortion are nearly always present to some extent and, when any or all are severe, cause a certain amount of lost service time. These interruptions are of relatively short duration and, furthermore, there is enough overlap in the normal times of usefulness of the several frequencies available, so that shifting to another frequency may give relief. There is, in addition, a kind of interruption which from the standpoint of continuity of service is more serious. At times of disturbance of the earth's magnetic field, known as "magnetic storms," short-wave radio transmission is generally subject to such high attenuation that signals become too weak to use and sometimes too weak to be distinguishable. These periods affect all the short wave lengths in use and may last from a few hours to possibly as much as two or three days in extreme cases. They are followed by a recovery period of one to several days in which transmission may be subnormal.

The cycle of events which accompanies magnetic storms is shown graphically in Fig. 14. It is apparent that the disturbances take about a day to reach their greatest intensity and the recovery to normal takes several days.

Experience indicates that on North and South routes such

as between North and South America, the interruptions associated with magnetic storms are less severe and of shorter duration. Transmission paths which pass through the polar

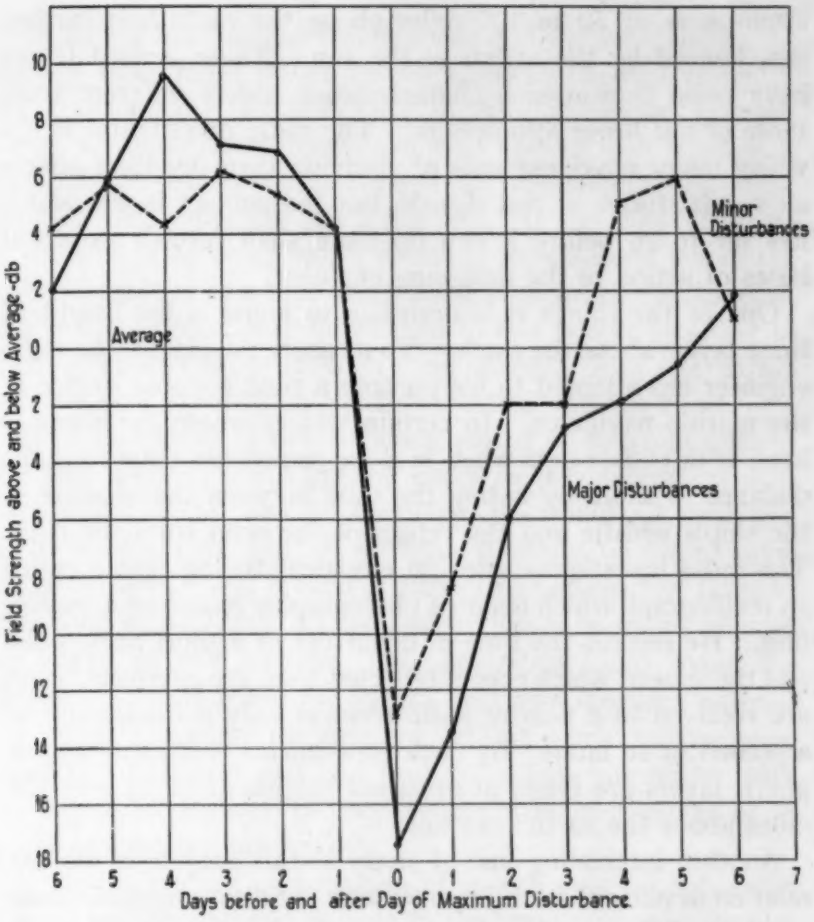


FIG. 14. WEAKENING OF RECEIVED SHORT-WAVE SIGNALS AT TIMES OF MAGNETIC DISTURBANCE.

regions where the Aurora Borealis is common seem to be most affected.

All these vagaries of short-wave transmission, including

diurnal and seasonal variations, fading, distortion, and magnetic storm effects, appear to be caused by or dependent on the characteristics of the earth's upper atmosphere at levels far above those subject to direct meteorological observation. The atmosphere at 50 to 100 miles above the earth is a rarified gas, ionized by the action of the sun. These ionized layers have radio transmission characteristics widely different from those of our lower atmosphere. The radio investigator is devising many novel methods of studying them by their effects on special forms of test signals, but the subject is one which has far to go before it can do more than furnish empirical bases of action to the designing engineer.

One of the things it is desirable to know is the height of these layers above the earth. To measure the height, the radio engineer has adapted to his purpose a time honored device of the marine navigator. In certain waters where the shore is lined with cliffs, pilots when in a fog sometimes determine the distance to shore by noting the time between the blowing of the ship's whistle and the return of the echo from the cliffs. The radio investigator uses an electrical timing device called an oscillograph which makes a photographic record on a moving film. He records the time of departure of a short radio pulse and the time at which echoes reflected from the overhead layers are received in a nearby radio receiver only a thousandth of a second or so later. By such experiments, reflecting atmospheric layers are found at apparent heights of 70 to over 300 miles above the earth's surface.

Another interesting line of study in this subject is the correlation of natural earth currents with variations in radio transmission. There are electric currents flowing in the earth much as there are natural currents of water in the ocean. A recording galvanometer connected by a telegraph wire between two ground connections separated by a few miles or more may be used to record the difference of potential between these points which is a measure of the current flow. The larger variations

on such records are found usually to coincide with poor short-wave radio transmission.

Privacy

So far we have considered methods and devices designed to fashion from radio waves speech highways having many of the transmission characteristics of wire telephone circuits. There are other characteristics of wire circuits with which it is desirable to endow radio circuits for commercial telephone service. An important one is privacy. If the wire telephone is thought of as being like a speaking tube system where the voice is confined to a pipe and guided from speaker to listener, the radiotelephone may be likened to two people shouting to each other or talking through megaphones. Any one within hearing may listen in on the conversation without effort.

If two members of this audience, seated on opposite sides of the hall, were to stand up and carry on a conversation with each other in the English language, we would all hear and understand it. In fact, to a degree it would be forced upon our attentions. But if each of these two persons had brought with him, we shall say, a Laplander to whom he might whisper his questions and answers, the Laplanders could speak the translated words across the hall in their own language without our being the wiser for listening, unless perchance we were especially intrigued and had brought a Lap interpreter with us. A radiotelephone privacy system may be thought of as a sort of electrical interpreter.

Although perfect transmission of speech may be noticeably marred by the slightest defects in the transmission system, it is remarkable that speech currents may be subjected to severe distortion without complete sacrifice of their intelligibility. This ruggedness of speech currents is the principal stumbling block in the approach to the question of disguising speech to make it unintelligible. In developing privacy systems for use

in transoceanic radiotelephony it has been necessary to devise means for converting speech into meaningless sounds, but in such a way that they may, by proper apparatus, be converted back into their original form at the receiving end. One of the simplest forms, by suitable modulation and filtering processes, inverts the entire speech frequency band, turning the bass into treble and the treble into bass. The result is to make English sound like some outlandish foreign tongue. A second inversion at the receiving end puts it back into its original form. Other more complicated systems divide the speech frequency band into several parts by means of electrical filters and then transpose these parts with reference to each other. Here again, retransposition at the receiving end brings back the original.

World Telephone Network

One of the most interesting of the activities of a development engineer is to study the probable future trend of an art and attempt to foresee new problems. In looking at world telephony with this attitude of mind we must see at once that it is now in a stage of rapid, sporadic growth and just beginning to enter the stage of integrated development and coordination which intracontinental wire telephone systems like our own in the United States have partly completed. Trunk routes such as North America to Europe may be expected to develop heavy loads of important traffic which require speed and reliability. That this trend is already under way is illustrated by the chart, Fig. 15, which shows the component parts of the growth so far occurring on the transatlantic system.

But what of the smaller outlying centers of population and local telephone development? How will they talk to the world? Speaking broadly, a radio path can be set up from one station to another in any direction simply by pointing antennas in that direction and using a wave length suited to the distance and time of day. It is not difficult to envisage,

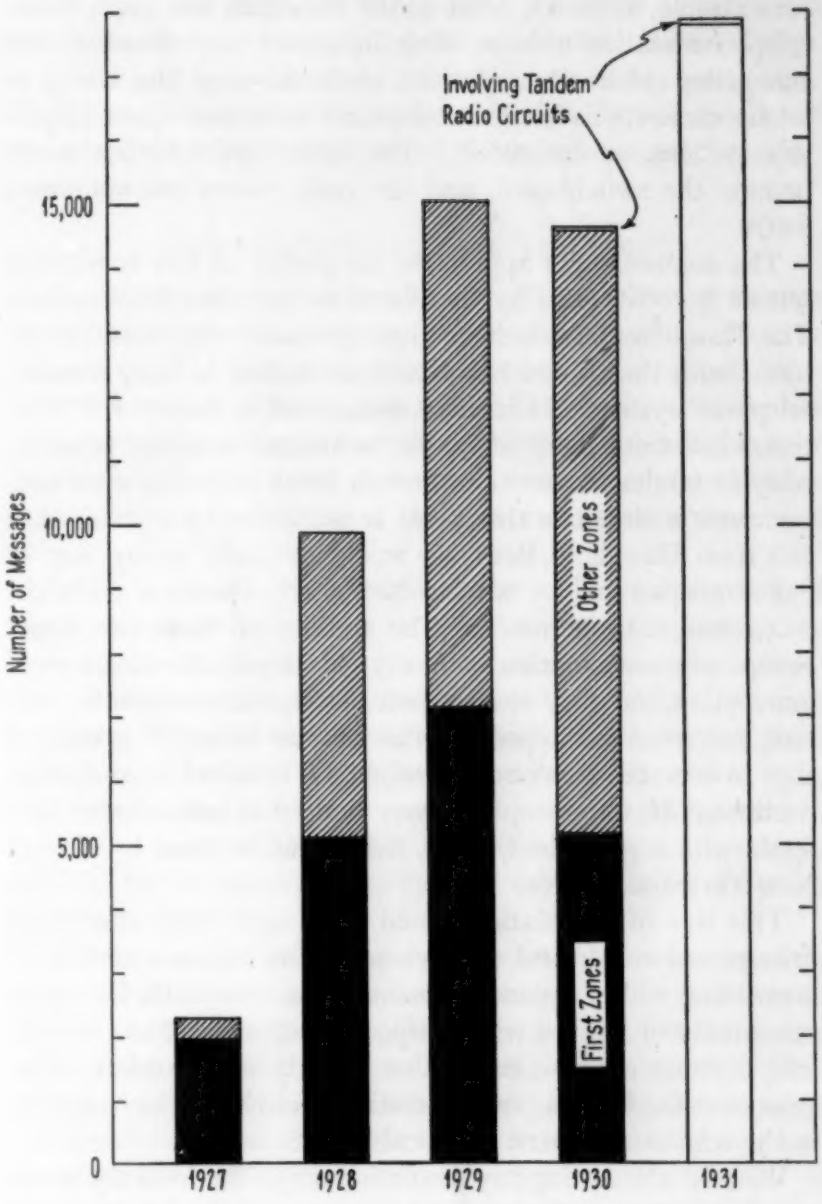


FIG. 15. GROWTH OF TRANSATLANTIC RADIOTELEPHONE TRAFFIC.

for example, at such a point as the Hawaiian Islands, a radiotelephone station able to work in almost any direction and connecting with other stations scattered over the world to set up connections between telephone users near these respective stations, as demanded. The luminiferous aether would become the switchboard, and the radio waves the operator's cords.

The engineer may appreciate the poetry of this conception but he is constrained by the liberal rather than the fine arts. The Hawaiian Islands have their greatest community of interest with the United States and are linked to it by a radiotelephone system. It is more economical to handle the occasional call from the Mid-Pacific to another outlying point by relay or tandem connection through trunk routes to some center where a circuit to that point is available. For example, a call from Hawaii to Bermuda would naturally go by way of San Francisco and by wire to New York whence a radio circuit connects to Bermuda. The stations on these two island groups are not sufficiently powerful for reliable direct communication, but they easily reach the nearest continental centers, and these are joined by efficient wire lines. It is evident that over-water trunk routes might be involved in such connections. If, for example, it were desired to interconnect Bermuda with a point in Europe, this might be done by way of New York and London.

This line of speculation would tend to indicate that radio links pieced end to end with wires are the ultimate method of connecting widely separated points. But Australia has great community of interest with antipodal England and has its only long distance overseas connection directly with London. Circuits over the longest possible distances obviously have a place in the scheme and merit technical study.

Without attempting any predictions as to the form the world telephone network may ultimately assume, it seems clear that (1) radio links may be called upon to interconnect with other

radio links and must, therefore, be made more perfect than would be necessary simply for communication between their terminal wire networks and (2) main trunk routes tend to become so important that their need for reliability and excellence may well tax the capabilities of the telephone art for some years to come.

Intercontinental Wire Telephony

On the important route between North America and Europe the capabilities of both long- and short-wave radio in their present stage of development have already been enlisted. Together they give more reliable service than could either alone. Recent developments in the submarine cable art have brought it also into the field and preliminary steps have already been taken toward the laying of the first transatlantic telephone cable.

In its technical system aspects, the cable shares many of the problems of the radio. Intermediate repeater stations are not at present practicable and the entire attenuation of the path must be made up by terminal amplifiers. Voice-operated switching systems are necessary. Reducing the attenuation offered by the cable to the higher frequencies essential to voice transmission has been made possible by extended researches in the field of special materials for insulating and electrically loading the single conductor type of cable used for deep sea conditions.

Whether submarine cables and new overland wire routes can ultimately take over a large part of the field of intercontinental telephony which radio has pioneered, or radio will be so improved as to maintain its place, only the future can tell. But it seems quite certain that a new era in long distance telephone communication has definitely opened and that research and development will again be expected to turn the miracle of today into the commonplace of tomorrow.

Ralph Bown

Picture Transmission and Television

A lecture delivered at the Lowell Institute, Boston, Massachusetts, January 15, 1932.

IN PREVIOUS lectures of this series, you have heard almost exclusively about the problems encountered in transmitting signals to be perceived by the ear. It is my purpose to-night to tell you about the problems encountered when our electrical communication systems are used to carry signals to be perceived by the eye. At the outset let it be clearly understood that there is nothing in our communication channels, whether these be metallic wires or the hypothetical ether, which differentiates between messages which originate as light or as sound, or which must be received by the eye or by the ear. In every case, the transmission medium carries electrical signals, that is, electrical currents which vary from time to time in intensity. Whether these signals shall be translatable into light or into sound is a question of what kind of terminal apparatus is used in conjunction with the communication channel. This does not, however, mean that a communication channel which has been established and engineered for the transmission of signals originated by sounds will necessarily be satisfactory or adequate for the transmission of signals originated by light. There are characteristic differences between the kind of sound signals that we are interested in transmitting and the kind of light signals that we wish to translate into and recover from electrically transmitted signals. These differences go back to certain fundamental characteristics of our human organs of sight and of hearing, and for a complete understanding of these, we must take a few minutes to discuss the eye and the ear.

Sounds are essentially "single track" signals. The vibrations of matter which are detected by the ear and the auditory

nerve constitute a single sequence of pulses or variations in intensity following one after another, differentiated from each other only in frequency and intensity. Consequently in the transmission of sound signals by electricity, a single electrical channel, such as a wire, is adequate, provided only that it is capable of conveying signals rapidly enough and without distortions such as those of intensity or of the relations of one signal to another in time; that is, in proper phase relation. When we consider the eye, we find a very different state of affairs. Our visual signals originate not along a single channel, but along a vast number, reflecting the fact that our visual field of perception is spread out into two dimensions, that is, it has *area*. Let us refer to Figure 1, which is a representative picture, such as is presented to the eye at any instant, and which we might wish to transmit to a distant point by electrical means. This may be analyzed into a very large number of small elements, each of uniform brightness, but which may differ in brightness value from any of the elements adjoining it. In order to appreciate this picture all of these elements must be perceived in their relative values *simultaneously*. In the human eye we have a light sensitive device capable of sending to the brain just such a group of simultaneous impressions. An image of the picture or scene is formed upon the back of the eyeball or retina by means of the crystalline lens, as shown in Figure 2. The retina consists of an extremely large number, many millions, of small separate light sensitive elements, called rods and cones; each so small that the images of all the ordinary objects with which we are concerned in our everyday life are divided up into imperceptibly small elements, in the same manner but to a much more refined degree than the little squares shown in Figure 1. From each of these sensitive retinal elements a separate nerve fibre goes through that cable or bundle of nerve elements called the "optic nerve" to the brain. As the scene presented to the eye changes from instant to instant, the signals sent from the light sensitive elements through the fibrils of

the optic nerve also change. If we admit, for the sake of argument, that each of the millions of nerve fibrils in the optic nerve is a conducting channel similar to the single auditory nerve, then we may say that the job of the optic nerve is to send *millions* of sequences of "sounds" while the auditory nerve is sending only a *single* sequence of sounds. Or to put it in another way, if our sense of vision were only that of the most primitive organisms, which appreciate merely variations of light, but have no optical system provided by which images may be formed, then the communication channels between the eye and the brain, and the ear and the brain, could be essentially the same.

If our technical development of image transmission systems were bound to slavishly follow the examples set by nature, we would proceed to devise picture and image transmitting systems in which, in place for instance of a single telephone wire, we bound up into one cable some thousands or even millions of wires, furnishing this cable at the sending end with an artificial retina or mosaic of light sensitive elements which would send an appropriate electrical signal from each small element of the image upon it.

There have not been wanting inventors who have proposed to do just this thing, that is, to build what are called "multichannel" picture transmission systems. The number of electrical conductors required is, however, so enormous for a picture containing any useful amount of detail that such systems have, by general consent, been agreed to be quite impracticable. Instead, all picture and image transmitting systems which have met with any success, have done with signals originated by light from a picture exactly what we do with signals originated by sound; that is, they send them over the communication channel in sequence, that is, one after another. Thus to illustrate from Figure 1, the light signal originated by the small element in the upper left-hand corner is transmitted first, then the signal from the next adjacent element to the right followed by

FIG. 1. PICTURE DIVIDED INTO SMALL ELEMENTS, TO ILLUSTRATE THE PROCESS OF SCANNING.

FIG. 3. ALKALI METAL PHOTOELECTRIC CELL, AS USED IN ELECTRICAL PICTURE TRANSMISSION.

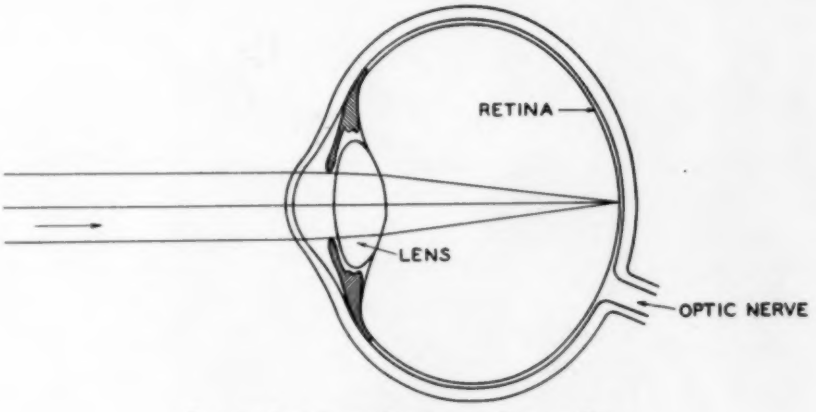


FIG. 2. SCHEMATIC SECTION OF HUMAN EYE.

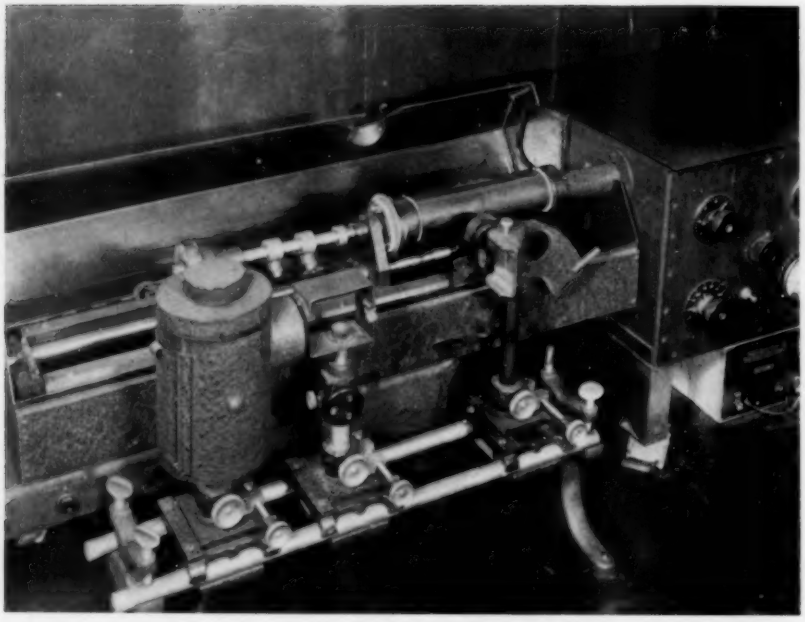


FIG. 4. PHOTOGRAPH OF SCANNING DRUM USED IN PICTURE TRANSMISSION.

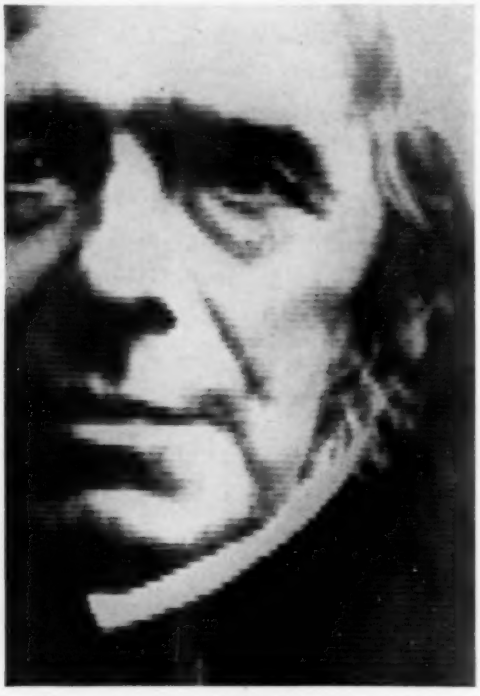


FIG. 6. ENLARGEMENT OF SMALL SECTION OF ELECTRICALLY TRANSMITTED PICTURE.

the 3d, 4th, 5th, and so on, and then in turn by the signals from all the elements in all the rows and columns of the picture. The process of picking up signals from each element of a picture in turn, translating what is in vision a simultaneous presentation into a series of presentations, is called "*scanning*," an operation which is fundamental to all present day systems of electrical picture transmission and television.

Now there is a fundamental consequence of this process of scanning. This is that the transmission of all of the signals which convey the characteristics of a picture or scene takes *time*. Those characteristics of a visual impression which, as compared to an auditory impression, demand *space*, can be met, where a process of scanning is used, only by calling upon the other one of our fundamental variables, namely *time*. We shall see as the problem develops, that this requirement for time may dominate our task in either of two ways. Either we must take a considerable overall time for the transmission of a picture, say a matter of minutes for a picture which can be seen in the flash of an eye, or our communication systems must be so built that they transmit signals at enormously higher speeds than are necessary in the case of sound.

With this introduction, we are prepared to discuss understandingly the two chief developments in the electrical transmission of images, namely the electrical transmission of pictures, and television. These two developments are, in many of their fundamentals, closely similar to each other. They do, however, differ in this fundamental respect, that in the case of picture transmission, the transmission is relatively slow, and practical systems have been adapted to operate at the speeds which are set by communication channels already in existence and engineered for the transmission of sound, that is telephone lines. On the other hand, any television transmission must be so rapid that the transmitted image runs with the scene itself, and for this purpose, communication channels adequate for

sound are hopelessly left behind in the race, and new and extraordinarily severe communication requirements must be met.

The Electrical Transmission of Pictures

In the time at my disposal, it will not be possible nor is it appropriate that I attempt to give a history of the subject of picture transmission, nor that I attempt to describe all the present-day forms of apparatus. I shall instead select one, namely that now in operation between a number of the principal cities of this country by the American Telephone and Telegraph Company. I shall in this discussion, however, plan to emphasize the functions of the various parts of this system rather than the particular form which these structural elements take, so that you may carry away an idea of the essentials of the problem, on the basis of which you will be easily able to understand other methods of meeting the same fundamental requirements.

The first essential for a picture transmission system is a device corresponding to the retina of the eye, or, since we shall assume a method of *scanning* or presentation of all parts of the picture in sequence, the equivalent of a single light sensitive element of the retina, a rod or cone. We must have a light sensitive device whose reaction to light takes the form of producing an electrical current. For this purpose, we use today the photoelectric cell, which makes use of a phenomenon first discovered by Heinrich Hertz, namely, that certain substances become electrically charged, when light shines upon them or, as we now put it more specifically, give off electrons. Photoelectric cells, a typical sample of which is shown in Figure 3, now used in picture transmission, consist of glass bulbs similar in some respects to those enclosing filaments of incandescent electric lamps or the now familiar vacuum tubes used in wire and radio communication. In such a glass bulb, which is evacuated to a low gaseous pressure, is a cathode of alkali metal, such as potassium or caesium. Standing opposite to the cathode is a metal collector which may be a wire ring or a

grid, which is also connected through a leading-in wire to an external electrode. If the two electrodes are connected together through a galvanometer, no current is observed when the cell is in the dark. When light falls upon the alkali metal cathode, a current flows. This current has two valuable characteristics for our purpose. It is proportional in strength to the intensity of the light, and it follows the variations of intensity of the light practically instantaneously. This current has, however, a very serious defect which is that it is excessively small, thousands of times smaller, under any practical illumination such as the light reflected from a picture, than are the currents which are produced by a telephone transmitter, and which all our existing telephone lines are fitted to carry. While the photoelectric cell has been known for a matter of thirty or forty years, it is this particular limitation which has prevented its use in picture transmission, and thereby has postponed the practical transmission of pictures to a very recent date. What was needed was exactly the thing which was required to make long distant telephony possible; namely, a "repeater" or amplifier which could step up small currents to large values. The amplifying device which has made this possible is the three-electrode vacuum tube, which has come into such enormous use with the expansion of long distance telephone service and the development of radio. By its means, the faithful but minute photoelectric currents are boosted in value by thousands or millions of times, and become acceptable to our telephone lines. The "eye" of our present-day picture transmitting systems therefore consists of an alkali metal photoelectric cell with which is associated a vacuum tube amplifier system; the whole constituting a device which, when illuminated by a sequence of *light* signals, delivers to the telephone line a sequence of *electrical* signals similar in intensity to these signals which are originated in the telephone transmitter and which are ultimately to be recreated as sound.

The second element of a picture transmission system which

we shall consider is the practical means for *scanning* the picture. One method of scanning, which is familiar to everyone, is that exemplified by the back and forth motion of a typewriter carriage. If we place our picture, which is to be transmitted, on a typewriter, and focus upon it a small bright spot of light and then place close to this spot of light a photoelectric cell, it is readily seen that as we punch the spacing key different elements of the picture come opposite the spot of light in turn, and our photoelectric call with its associated amplifying system would deliver currents of different strength to the telephone line. The reciprocal motion of the typewriter carriage is, however, mechanically inefficient because of the changes of direction of motion and the frequent stops, and has not often been used in picture transmission. Figure 4 shows a photograph of the scanning device which has been most commonly employed. This is a cylinder around which the picture to be transmitted is tightly wrapped. Means are provided for rotating the cylinder and at the same time moving it along parallel to its axis, or, sometimes, the light source which concentrates the small bright spot of light on the cylinder is moved along while the cylinder merely rotates. In either case, the result is that the small spot of light describes a helical course around the cylinder and in its complete progress from one end to the other covers in succession every part of the picture, thus building up a sequence of signals. So much for the sending end. At the receiving end, this long procession of signals must be reassembled in rows and columns exactly corresponding to the positions of the picture elements which originated them. For this purpose, an exactly similar scanning device is demanded at the receiving end, that is, another rotating cylinder on which is tightly wound some sort of receiving surface upon which can be impressed spots of varying intensity or reflecting power.

With this brief statement, we can dismiss the mechanical features of the scanning process, leaving for more detailed discussion two further features: first, the means for translating

the incoming electrical signals into light and shade in the received picture, and second, the means for assuring that the two scanning mechanisms rotate in perfect step with each other, or are *synchronized*. Taking up the first of these problems, we shall assume at once that reception is to be made photographically; that is, we are to place upon the receiving cylinder a piece of photographic paper or sensitive film, and we are to expose it to a light whose intensity shall vary in accordance

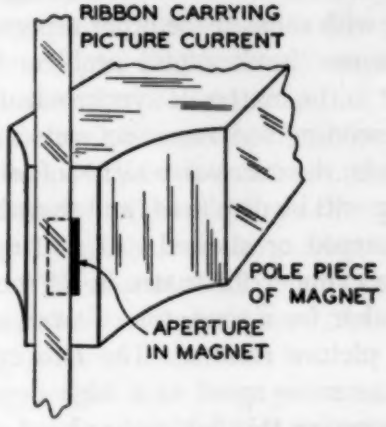


FIG. 5. THE LIGHT VALVE USED IN THE RECEPTION OF ELECTRICALLY TRANSMITTED PICTURES.

with the signals. We have therefore to produce, just as at the sending end, a small spot of light, but whereas at the sending end the spot of light is of constant intensity and the portion of it which is reflected to the photoelectric cell varies, the spot of light at the receiving end must itself fluctuate in accordance with the signals. In the picture transmission system which we are describing, this variation of the intensity of the light is brought about by what is called a "light valve." The essentials of this are shown in Figure 5. There is first of all a narrow metal ribbon through which the incoming picture currents pass. This ribbon stands directly in front of the pole-piece of a magnet. In this pole-piece, there is a small aperture through

which shines an intense light which is focussed into a small spot which falls on the sensitive film. When there is no current passing through the narrow ribbon, the ribbon is so positioned as to obstruct all the light coming through the pole-piece of the magnet. When, however, a current flows through the ribbon, the interaction of the current and the magnetic field causes the ribbon to move sidewise and so transmit more or less light to the film. This is a simplified account of the operation of the light valve, to which I shall return, discussing it in greater detail after dealing with some of the other aspects of the problem.

There remains one fundamental problem in picture transmission, and that is the matter of synchronization. If the two cylinders at the sending and receiving ends rotate at different but uniform speeds, the successive strips of which the received picture is built up will be displaced, and the whole picture, as a result, will be warped or skewed. If, during the process of transmission, one cylinder fluctuates in its speed, that is, goes faster than the other for a time, then slower, a local distortion or jiggle of the picture results. The two cylinders must in short rotate at the same speed to a high degree of accuracy. One method of securing this, which has been used extensively, is to operate the two ends of the picture transmission system by electric motors which are driven from the same source of high frequency current; this source being in turn controlled by an accurate tuning fork. This requires a separate communication channel from that used for the picture, and this method has been in part superseded by a method which has been made possible by the great advances in recent years in superaccurate forms of clocks. The "clocks" now used in the Bell System picture transmission system consist of tuning forks enclosed in constant temperature baths which, when adjusted to a given standard frequency, will maintain this frequency for long periods of time without varying enough to appreciably distort the picture. These forks in turn operate electric motors of the phonic wheel type, which are pulled back to speed or speeded

up as their poles attempt to get out of step with the electrical pulses delivered by the accurate tuning forks.

We are now ready to discuss the important matter of transmitting the electrical signals which go between the two rotating cylinders and the light translating devices associated with them. It has already been said that these signals are quite similar to those originated and utilized by telephone transmitters and receivers. Now historically the present practical picture transmission systems have been a very recent development, and an essential requirement they have had to meet is that their signals should not merely be similar to ordinary telephone signals, but that they shall adapt themselves rather accurately to certain characteristic limitations which modern telephone lines embody as a result of their having been engineered primarily for voice transmission. One of the reactions of the characteristics of ordinary telephone lines on picture transmission is the matter of speed. We are not at liberty to run our picture transmission cylinders at any speed we want, for the simple reason that if we operate the cylinders too fast the signals run up to much higher frequencies than those present in the voice. The telephone lines being only built to carry voice frequencies, would not transmit these high speed signals and detail would be lost in the pictures. The electrical signals which are originated either by pictures or by the voice can be analyzed into what is known as a Fourier series, which shows that they correspond to the superposition of a large number of different frequencies of vibration. In the case of the voice, these frequencies run from 200 or 300 per second up to some thousands per second. For speech to be intelligibly transmitted, we must transmit a range of frequencies or a " frequency band " as it is called from about 300 to 3000 cycles or back and forth variations per second, and ordinary telephone lines are set up to carry just this band. Frequencies above this higher figure do not go across, and frequencies below this lower figure, not being necessary for speech, have been neglected in telephone engi-

neering and can now be transmitted only by special arrangements of line elements.

Now first of all, with regard to the question of speed of picture transmission. The picture cylinders must be rotated at a sufficiently low speed such that the finest picture elements which we wish to transmit do not cause variations of current occurring more than 3000 times per second. What the upper limit of this speed shall be is a simple matter of arithmetic, in which the factors are the size of our little spot of light, which represents the smallest detail which can be distinguished in the scanning operation, and the number of rotations per second of the cylinder. In the American Telephone and Telegraph Company system, to give a practical figure, the small spot of light is 1/100″ square. The picture transmitted is 5 inches × 7 inches in size, and the overall time for sending this over a telephone line is approximately seven minutes. This is well below the upper limit of speed which may be computed as indicated above. An enlarged reproduction of a portion of such a picture is shown in Figure 6. (*Figure 6 faces page 121.*)

In general, any telephone line which will transmit telephone messages faithfully in all respects is suitable for the transmission of pictures by a system, such as that we have described, which has been carefully fitted into the frequency limitations characteristic of telephone transmission. However, picture transmission imposes certain special requirements on a transmission system different from those for voice transmission. The picture constitutes a permanent record of conditions during the period of transmission, whereas the characteristics of the voice signals are to a large degree forgotten shortly after they are perceived. Thus in listening to a telephone conversation, if the intensity rises and falls by a small amount, we either do not notice it or assume that the speaker is moving his head with respect to the transmitting instrument. If small disturbances, such as extraneous noise, or let us say a cough, interrupt the speech, they are disregarded. If there are slight echoes,

either actual sound echoes or echoes in the electrical system, they are discounted. With a picture, however, if the transmission level changes,—the phenomenon of "fading" in radio —the resultant picture shows permanent areas of different intensity. Disturbances of transmission which we call "static" in radio show as permanent blotches, and echoes show as repeated images; all of which may easily destroy the value of the picture. So, as a matter of practical transmission engineering, it has been found that the transmission lines must be maintained to a more uniform level of performance for picture transmission than was formerly considered necessary in voice transmission. For the same reason, radio, with its many electrical disturbances, has never been found as suitable for picture transmission as have wire systems.

There is one other point connected with transmission, and that is how the very low frequencies are transmitted. These, as already stated, are not present in the voice and the telephone lines do not transmit them. In a picture, however, frequencies will be present from that represented by the speed of rotation of the cylinder, say one cycle per second, up. Now in order to transmit all of these low frequencies, we make use of the same scheme which is used in putting signals on to the air in wireless telephony. That is we use the picture signals to modulate or to vary the intensity of a steady high frequency current, which is called the "carrier." In the case of picture transmission, we choose a carrier lying in the voice frequency range, say about 1500 cycles per second, and by means of a modulating device we impress upon this the picture signals, with the result that they are now spread out into frequencies above and below the carrier value in what are called "sidebands," the lower one of which now lies wholly above that of the frequency region which the telephone lines do not transmit. Now let us return for a minute to the light valve, which has been described above as opening and closing in proportion to the strength of the signals. We have to modify our description now to this extent that in-

stead of imagining the valve to be opening and closing relatively slowly in the direct proportion of the original light signals, the ribbon actually vibrates at this carrier frequency, with varying amplitude. The impression upon the photographic sensitive surface, therefore, consists of a band of photographic action in which the intensity is varying some 1500 times per second, whereby the picture, examined with a microscope, would exhibit fine strips or cross hatchings. These are however in practice so smoothed out by the finite size of the spot of light as to be rarely detectable. Mention of them is however necessary to build the complete story of the production of the picture.

With this necessarily somewhat superficial description of a typical picture transmission system, we must pass on, for we still have the second of our problems—that of television, to discuss. Before proceeding to this, however, something should be said about the field of usefulness of picture transmission. In general, of course, a photo-telegraphic system finds its primary use in the transmission of information in which form and arrangement are essential factors. In this category fall primarily, pictures, such as news photographs; but there are many other subjects logically calling for transmission by such a system. These are construction drawings, advertising material, particularly such as embody pictures, special arrangements of type, or a large range of significant figures which might readily be misinterpreted over an ordinary telegraph system. An excellent illustration of this is given by financial advertisements, carrying numbers or prices of stocks and bonds which must be simultaneously advertised over the whole country. Contracts and legal manuscripts of all sorts in which absolute facsimile fidelity is required are at times profitably routed over the picture transmission system. It is, however, to be recognized that the elements of time and of expense are of dominating importance in electrical picture transmission. Even for those pictures and documents which must be transmitted with the perfect fidelity which the picture transmission

system provides, the use of electrical communication systems is only indicated if the information must be secured *sooner* than it can be through the mails, or particularly now, by air mail. The urgency of securing accurate information must be matched against the cost of electrical transmission, which at present is somewhat greater than the cost of telephone conversations occupying the same length of time. Thus in the system which we have discussed, if all of the pictorial information can be embodied in a 5 inch $\times$ 7 inch picture, the transmission costs cannot reasonably be expected to be less than those for a seven minute telephone conversation, which, over such distances as New York to San Francisco, is of necessity much greater than the postage rates on the same material.

Television

By television is ordinarily understood the transmission by electrical means of moving images at such a speed that the images are produced concurrently with the original scene, that is, the actions in the reproduced image occur not only *at the same speed,* but *simultaneously* with the original action. We can no longer, as in the case of picture transmission, allow a matter of minutes for the picture to be developed. The image must, like the image on the retina of the eye, be complete at any instant and capable of complete change from one instant to another. In order to meet this requirement absolutely, it would be necessary to copy the multi-channel communication system used in the optic nerve, that is, the process of scanning which has been described in connection with picture transmission would be inapplicable. There is, however, a loophole, which does permit us to use the process of scanning, which is the only practical one for image transmission. This loophole is provided by the fact that the process of vision in the human eye is incapable of distinguishing between images which are continuously complete and images which are presented for only a part of the time, *provided* the intervals between these images

be short enough. The phenomenon in question is called "persistence of vision" and is used by us whenever we view an ordinary motion picture. This interval between successively presented pictures, which causes them to appear continuous, is about 1/20 of a second, so that in our immediate problem, if the scanning operations and the transmission of signals can be performed for a complete image or field of vision in 1/20 of a second, the signals can be transmitted in sequence, and the problem of television remains essentially similar to that of picture transmission. There is, however, the important condition to be met that the speed of the various operations involved must be enormously increased over those satisfactory in picture transmission.

In order to carry with us an idea of the speeds of scanning and transmission which are called for by television and how these compare with the kind of transmission with which we are familiar in existing practical communication lines, such as are used in telephony, let us take the kind of picture we have already considered, that is, the 5 inch $\times$ 7 inch picture scanned in 100 strips per inch. This picture contains 100×100 or 10,000 elements per square inch or 350,000 elements altogether. It is transmitted in seven minutes, and the "sideband" or range of frequencies into which the transmitted signals may be analyzed, is approximately 400 cycles per second. Now if we are to transmit this same picture in 1/20 of a second, this frequency band must be multiplied by the ratio between seven minutes and 1/20 of a second, which is about 8000 times, giving a frequency band of over *three million cycles* per second. Compare this with the frequency band of approximately 2500 cycles on which intelligible speech may be transmitted, or the 5000 to 8000 cycle sideband which is used by our radio broadcasting stations, and we see at once that the transmission requirements as expressed in figures are extraordinarily great. The problem of television is affected by this requirement in two ways. First of all, communication channels are called for

whose performance is altogether outside the range of anything which has heretofore been developed or used. In the second place, when we view the economic aspects of the problem, we must recognize that communication channels cost money, and that, broadly speaking, it is inevitable that television of the quality we have just assumed would pre-empt communication channels otherwise occupied by a thousand or more telephones or broadcasting stations, and that the cost in dollars and cents of television transmission must therefore be multiplied by a large ratio.

The problem of achieving television has been met, insofar as it has been met up to this time, not by developing or using apparatus and transmission channels which can carry the kind of image we would *choose,* because adequate apparatus and transmission lines have not been available, but by limiting ourselves to such primitive and coarse grained images as we *can* generate, with means provided by the present state of physical science, and can transmit over communication channels which are available. We crowd into a 20th of a second all that our present knowledge of physical phenomena and technical methods will permit; and the future of television promises to be a long pull to squeeze more and more into this 20th of a second fixed by persistence of vision.

The seriousness of the problem of television has just been illustrated in terms of transmission requirements, but it is not alone in the transmission that we meet with grave difficulties. The terminal apparatus of television, which converts light into electrical signals at one end and electrical signals back into light at the other, is also in difficulties when the number of image elements is made large enough to be of real value. One great difficulty has to do with the *amount* of light with which we must work at the two ends of the system. At the sending end, the amount of light which will fall on the photo-sensitive device is that which comes through some kind of small aperture of the size of an image element. As the scene to be trans-

mitted is divided into more and more elements, these elements correspondingly decrease in size, and the amount of light acting on the photoelectric cell or other device soon becomes so small as to produce no useful effect. At the receiving end, we have a similar situation in that as the number of light producing elements out of which the picture is built becomes larger, the elements each become smaller and the time during which they can be turned on is decreased, consequently the brightness of the image which is built up at the receiving end always threatens to drop below the threshold of satisfactory vision. There are other obstacles to the attainment of high quality television, but these are sufficient illustrations of the general nature of these problems, and we may now profitably proceed to a description of the means by which our present day television has been attained.

As in the electrical transmission of pictures already described, the general scheme by which television is attained is by means of scanning devices coupled with light sensitive means at the sending end to convert light into electrical signals, and coupled with light producing means at the receiving end to convert electrical signals into light. Between the two ends is an electrical communication channel, and the two ends are operated in synchronism by some appropriate means. In order to present to you concretely what particular means have been found successful, I shall again describe one particular system, again a system as developed by the American Telephone and Telegraph Company and used in its first demonstration of television in 1927.

The scanning device used in this apparatus and in the majority of television apparatus thus far developed is a rotating flat circular disc in which is a spiral of small holes as illustrated in Figure 7. Close to the disc is placed a small aperture of approximately rectangular shape of such a size that as the disc rotates about its axis, only one hole of the spiral at a time is exposed by the aperture, and as the holes follow each other,

adjacent narrow strips across the aperture are scanned until, on a complete revolution of the disc, the whole area is covered. All of the light which is to reach the photo-sensitive device at the sending end or the eye at the receiving end must go through these holes. Let us now direct our attention to Figure 8, where the sending end apparatus for the television system is shown in skeleton form. The scanning disc is readily recognized toward the left of the picture. In this case, it is a disc 15 inches in diameter, provided with 50 holes in its spiral. Off to the

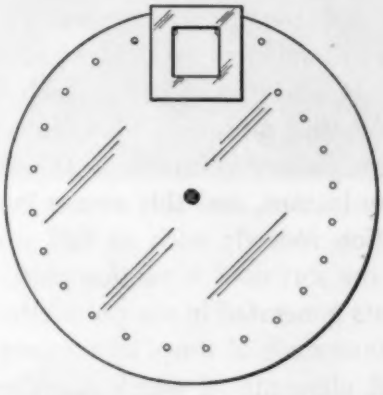


FIG. 7. THE SCANNING DISC, WIDELY USED IN TELEVISION.

right of the figure is an intense source of light; in this case, a high power arc lamp. By means of condensing lenses, the light from the arc is concentrated in a spot on the back of the disc. A small part of this light goes through the particular hole of the disc which is behind a field limiting aperture and extends as a narrow pencil out to the left and falls upon the face of the subject. As the disc rotates at 20 revolutions per second, successive pencils of light sweep across the face so that it is completely scanned once during each revolution. Slightly to the left of the scanning disc and arranged in an inverted "U" form are seen three large photoelectric cells similar in nature but of much larger size than those used in picture transmission

apparatus. These pick up the light reflected from the face and produce electrical currents whose intensity at any instant is governed by the reflecting power of the object on which the spot of light is then resting. This method of scanning is called "beam scanning" and is a scheme which has been devised particularly for television purposes in order to make the most efficient possible use of the light. While the spot of light is exceedingly intense and throws a relatively large amount of light to the photoelectric cells, it rests for such a short time over any spot, such as the eyes of the sitter, as to give an average illumination which is not too great for comfort. Ordinarily, of course, objects are illuminated by light which is constantly falling upon every part, and it is indeed possible to use a scanning disc with an object thus uniformly illuminated, but this illumination must be everywhere as intense as the small spot which is being used at any instant, and this means in television a very intense illumination indeed; such as full sunlight or intense flood lighting of the sort used in motion picture studios.

Electric currents generated in the photoelectric cells are next amplified many thousands of times by vacuum tube amplifying systems, the first elements of which are shown in the small boxes adjacent to the large photoelectric cells, and these currents when boosted to the magnitude of ordinary telephone currents are ready to be sent over a proper communication channel.

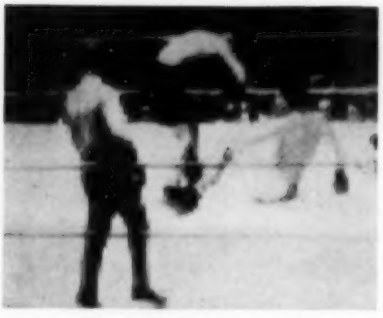
Going now for simplicity of discussion to the scanning means used at the receiving end, let us examine Figure 9. Here we have again a scanning disc with a spiral of holes with a small rectangular aperture in front which exposes only one hole at a time. Behind this disc is a light source, which in this case is an electrical glow lamp containing neon gas at a low pressure; this gas, when excited by an electric current, causes a glow of light to cover a flat plate electrode which is of the same size and shape as the aperture over the disc. In front of the disc to the left is shown the observer, who looks through the holes in the disc at the flat glowing area of the electrode. At any in-

FIG. 8. APPARATUS USED AT THE SENDING END FOR TELEVISION.

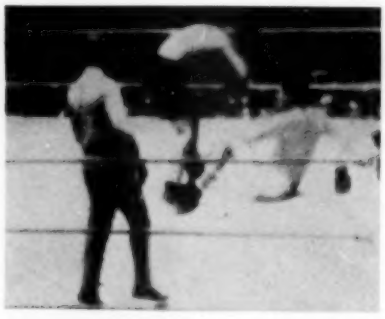
FIG. 9. TELEVISION RECEIVING APPARATUS.

Television images as they would appear if transmitted by usual methods over an ordinary broadcast band. 27 scanning lines, 600 elements, 5000 cycles.

With 40 scanning lines, using two ordinary broadcast channels, some improvement is noticed.



By using 72 scanning lines and ten ordinary broadcast channels, the appearance would be as above.



By using 120 scanning lines and employing twenty ordinary broadcast channels greater detail is gained as indicated in the group above.

FIG. 10. CHARACTER OF TELEVISION IMAGES CORRESPONDING TO DIFFERENT NUMBERS OF SCANNING LINES.

stant he sees, of course, only one hole and this hole is of the brightness corresponding to the intensity of the glow lamp at that instant. Since the disc is rotating at 20 revolutions a second, an observer is not conscious of the fact that he is seeing a single spot at a time. He sees the whole area of the aperture illuminated, but its brightness at any particular point is the brightness of the lamp at the instant when a scanning hole was at that point. Now if this receiving disc is rotating in exactly the same speed as the sending disc and is accurately in step or phase with the sending disc, and if further the variations in brightness of the glow lamp are accurately following the transmitted signals which originate in the photoelectric cells of Figure 8, then each point seen in the aperture over the receiving disc will correspond in brightness and position with the illuminated area in front of the sending end disc. In other words, the image will be recreated. It is obvious that the lamp which is used for receiving the electrical signals, in this case a neon glow lamp, must be extremely rapid in its action in order to follow the signals accurately, and it must be sufficiently bright so that with the 50 hole disc here shown 1/2500th of this brightness, which is all that one hole transmits, must still be bright enough to be satisfactorily visible.

Let us consider now the problem of synchronization. If the discs at the sending and receiving ends are going at uniform rates but not rotating at exactly the same speed, the image as received will drift out of " frame." If the discs are not rotating with a high degree of uniformity, the received image will waver in position and various parts of it may waver at different rates, introducing distortions of shape. The degree of uniformity of motion required for the two discs is very high. For instance, with the system under description, if one disc moves out of position by the width of a scanning hole, a distortion of the image will be easily noticeable, yet this deviation is only the distance which the disc moves in about 1/50,000th of a second. Synchronization in television, therefore, demands " clocks " or

identical control means for the two ends of extraordinary accuracy. In the system under description, this control has been achieved by using synchronous electric motors, which are driven by high frequency currents of the order of 2000 cycles per second, generated by vacuum tube oscillators and transmitted over separate communication channels from those used for the images. Looking ahead to the future, one of the requirements for widely used television systems appears to be the provision of widespread accurately synchronized electrical circuits. The first step in this direction has been made in the accurate timing of the alternating currents now widely used for lighting and power supply, and a simple means of television synchronization where the highest accuracy is not required, is to drive both the sending and receiving ends from the same alternating current lighting supply.

We now come to the problem of transmitting the television signals from one scanning apparatus to the other. Before describing the characteristics of the actual lines used, let us consider the requirements and how they are arrived at. As already pointed out, in the case of the electrical transmission of pictures, the method of attack is to decide on the size of picture and the number of picture elements which must be transmitted in order that *the picture may be satisfactory*. *Then* a speed of transmission is picked such that this number of picture elements may be transmitted over some existing available transmission system, such as a telephone circuit. In the television system now under description, the problem was dominated not by the kind of image one would *like* to send, but the kind of picture that could be scanned and sent in our fundamental period of 1/20 second, considering the limitations of the apparatus and the transmission channels. Now on surveying the size of photoelectric currents which can be generated, the frequency bands which could be transmitted by special telephone circuits and the available light sources which could be made to follow electrical signals at high speed, it was found at the time of

these experiments that a frequency band of about 20,000 cycles per second seemed a feasible thing to work to. If we work back, therefore, the arithmetic gives us a figure of about 50 holes as the number to be incorporated in our scanning discs. This means approximately 2500 image elements in our scanning rectangle. This is exceedingly small compared with the 350,000 which constituted a satisfactory number for transmission of a photograph for news purposes. What can we do with this small number of elements? An idea is obtained by noting that a coarse newspaper half-tone, which also consists of little picture elements, in this case dots of various sizes, contains 2500 elements in a rectangle about ¾ inch on the side. Now while not much of a picture can be included in a ¾ inch square of newspaper, it is true that if we restrict ourselves to a single face, we can get a recognizable picture with this number of elements. Accordingly, the first television transmissions, which met with any success, were transmissions of images of the human face. While in the several years which have elapsed since the first demonstrations the number of image elements has been slowly and laboriously increased (by a factor of approximately two) and wider transmission bands have been used, it is still the situation that satisfactory television transmission is restricted to one or at most two faces. While this is reasonably adequate for television in conjunction with the telephone, it is far below what we would like to have in television for purposes of home entertainment. It is however what we are now limited to by the capabilities of the best scanning and transmitting means which technical science has as yet produced.

A few words more about the transmission problem. The electrical signals produced by television scanning apparatus can, like those originating in sound, be transmitted over any kind of electrical communication system, that is, either by wire or by wireless, provided only that the band of frequencies transmitted is wide enough and is sufficiently free from irregularities in transmitting efficiency at the different frequencies or from

time to time. Thus in the experimental demonstration in 1927, television images were sent by wire from Washington to New York, and the attainment of greater distances is merely a matter of setting up telephone lines to carry the necessary frequency bands with sufficient freedom from distortion. At the same time that the wire demonstration was given from Washington to New York, a demonstration was given of radio transmission of television between the Bell Laboratories experimental radio station at Whippany, New Jersey, and New York City, a distance of 27 miles, with similar results. However, as was found at that time and must be recognized in general, radio is more subject to disturbances of transmission, such as fading, static and multiple transmissions due to electrical echoes, than is wire transmission, and therefore presents a somewhat more difficult transmission problem.

The above description covers the essential problems presented by a simple and relatively crude television system. While there have been some interesting developments beyond the simple one-way apparatus we have considered, such as two-way television, for use in conjunction with the telephone, television in color, the projection of television images to large size (although, it is important to note, with no more detail), the use of television methods for sending images from motion picture film, the time at our disposal will not permit discussing these in detail. Our consideration of the subject can accordingly be most profitably concluded by a few words about the possible future developments and future uses of television.

The outstanding physical characteristic of television which offers a fundamental difficulty in its development is that improvement means inevitably the transmission of many more image elements than any physical means now available can generate, transmit or recover. While no figure can now be agreed upon as representing a "satisfactory" number of image elements for a television system, the several pictures in Figure 10, which show how the delineation of an image depends upon

the number of elements, indicate clearly that this number must be very much higher than anything as yet attained in television. It is to be remembered that while in sound transmission, apparatus which will faithfully transmit the voice of a single person, will transmit equally well all the voices of a chorus, the situation with television is altogether different. As the number of faces is multiplied, so must the complexity of the apparatus and the transmission facilities be likewise increased. The problem of developing and constructing television apparatus to handle satisfactorily extended scenes such as are presented by athletic contests, public ceremonies or theater stages, is one the method of whose solution is not clearly visioned at the present time. Even when the means are discovered or developed, it appears inevitable that the cost must be relatively very high compared with any other form of electrical communication. The two-way television system in experimental operation by the American Telephone and Telegraph Company, which transmits only a single face in each direction, uses communication facilities which could otherwise be utilized to carry about fifteen telephone conversations, so that the cost of performing this relatively simple television task would, on a commercial basis, of necessity be many times that of ordinary telephony. The cost of transmitting extended scenes by television must, insofar as the communication channel cost is concerned, be tens or even hundreds of times greater than satisfactory sound transmission. These facts make the future of television, to a large extent, an economic question. What value will be placed by the public on the addition of sight to sound? This question in turn may be considered under two aspects; one, is what value is to be placed upon *simultaneity* of event and viewing, and the other is what value is to be placed upon the transmission of images by *electrical* means as contrasted with their transportation by other existing methods. In television used as an adjunct to the telephone, it is, of course, essential that the image be sent simultaneously with the sound by which the two-way conversa-

tion is carried on. In image transmission for purposes of entertainment, on the other hand, the element of simultaneity, which pertains to television in its strictest interpretation, is probably not generally necessary. As a consequence, many of the functions often thought of as belonging to television are really quite adequately taken care of by quickly transported motion picture film. If instead of carrying the motion picture film from place to place, motion picture images could be transported electrically by a television system, the choice between the use of a home motion picture projector and a television apparatus receiving film images from a broadcasting station would depend entirely on the question of cost and convenience. The comparison is similar to that between the possession of a phonograph and the possession of a radio set. Practically, the present radio provides a very large library of sound records and saves the listener the labor of changing records. Should television be so developed as to compare in simplicity and cost with the home motion picture projector about as the present-day radio does with the phonograph, its future as a form of entertainment would probably be assured. At the present time, the technical and economic obstacles appear to make such a consummation far distant.

HERBERT E. IVES

Utilizing the Results of Fundamental Research in the Communication Field

A lecture delivered at the Lowell Institute, Boston, Massachusetts, January 22, 1932

WHEN the suggestion of a course or series of lectures for the Lowell Institute on the application of science in electrical communication was first broached, the question of how best to cover so vast and diverse a subject, within the limits of seven or eight short lectures, immediately arose. It was finally decided to resort to the series rather than the course method and to handle the matter as is outlined on your program. Whether we succeed or not, what we attempted to do was to present first, in Dr. Arnold's lecture, something of the methods and processes by which science is being applied in the field of electrical communication, and to illustrate types of problems with which we in that field are confronted.

Following Dr. Arnold's address we have attempted, in the addresses of Dr. Fletcher, Dr. Bown, Dr. Ives and Mr. Otterson, to present first in Dr. Fletcher's address a picture of those fundamental problems in speech and hearing which are at the very base of that part of electrical communication which is telephony. The addresses by Dr. Bown, Dr. Ives and Mr. Otterson have sought to give you a glimpse of what is involved in one of the newer developments of telephonic communication and in a few of the by-product results which have developed in our attempt to advance and expand the main body of telephony and telegraphy through a well organized long continued application of scientific knowledge and scientific research.

In these last two addresses of the series Mr. Page and I will attempt to present, first, a general overall picture of how

we have utilized and are seeking to utilize the results of fundamental research in the communication field, and second, something of our picture of the social aspects of communication development and a bit of the philosophy which has guided us of the Bell System in our endeavor to broaden, to better and to cheapen the tool of electrical communication.

Arranging for presentation in this way has the possible risk of leaving you with an erroneous idea of the magnitude and scope of our scientific work and of the fields in which our maximum effort is applied. In a word, it may tend to leave you with the thought that our principal scientific interest is along the outlying fringe of electrical communication and in the region of the by-product satellites. Such is distinctly not the fact, as I shall indicate to you a little later. Our reason for choosing the particular topics which we did was partly because of the sheer impossibility of presenting a fair and interesting picture of our entire scientific activity in a limited number of detail papers; partly because of the inherent interest which resides in the newest things of applied science, and partly because some of these newer things combine in their solution the maximum of all that we now know about the possibility of applying scientific knowledge usefully. With this explanation and against the background of the preceding lectures it is my task this evening to attempt to give you in words, and without the aid of charts, slides or demonstration apparatus, an overall picture of the manner, method and extent to which we utilize the results of fundamental research in the field of electrical communication.

Before undertaking this task a word of explanation is required as to the meaning of the word "fundamental" in connection with research, as I propose to use it. In scientific parlance the word "fundamental" when associated with research has come commonly to designate that type of research which has to do with the acquisition of new knowledge dissociated from any idea of possible utilitarian application. In this sense

it is the type of scientific research work which is sometimes designated as "pure" research in contradistinction to "industrial" research. In this sense the use of the word "fundamental" is preferable to the use of the word "pure" because of the implication contained in the latter that all other forms of research are impure.

In the sense in which I propose to employ the term "fundamental" this evening, you should understand that it embraces not only all that is contained in the scope of its general usage but also embraces all that portion of scientific research which is fundamental to the application of science in the field of communication. Put another way, it embraces everything derivable in the way of new knowledge that is productive of the elements from which new or improved communication structures can be created.

Reduced to its simplest fundamental elements, every electrical communication system involves two main and essential elements, the terminal apparatus and the channel for transmitting electrical impulses between the terminal apparatus. In very simple communication systems these two elements are sufficient and whatever other things are required are merely in the nature of conveniences to facilitate operation. Where, however, as is the case in telephony generally, and in modern telegraphy to a large extent substantially, ability to make rapid interchange between different terminals is a primary requisite to successful operation, a third element, namely, switching machinery, becomes of fundamental importance.

The primary requirements for terminal apparatus are that at the transmitting end it should provide an efficient means of translating some form of non-electrical intelligence material into electrical impulses which can be transmitted over the connecting channel in an amount and of a character to be properly interpreted by the receiving apparatus. This latter apparatus must be capable of efficiently and correctly translating the electrical impulses from the distant transmitting station

into a form of non-electrical communication material which is directly relatable to the non-electrical communication material submitted to the transmitting apparatus. This non-electrical communication material delivered by the receiving apparatus may be substantially identical in form and character with that submitted to the transmitting apparatus, as is the case in telephony and its variants as they may appear in such things as broadcast sounds, or as is required in most forms of picture transmission and in some forms of telegraphy. On the other hand it may, as is the case with much of telegraphy, be in substantially different form from the exact non-electrical thing which is submitted to the transmitting apparatus. In this latter case, however, it must be of such a form and character as to be translatable into the exact arrangement of intelligence material as that supplied by the human being who proposed the originating message.

In a word, since the function of all electrical communication systems is to transmit to a distance, and substantially instantaneously, some one of the several forms by which human beings intercommunicate ideas, either directly by sight or sound when they are close together, or by non-electrical means when they are separated, the sending and receiving apparatus must be such as to accept and deliver the intelligence material without substantial impairment of form or context.

In addition to these primary translating requirements for terminal apparatus, there is a secondary requirement which in many cases assumes substantially the proportions of a primary requirement. This is the provision of some form of signalling device to attract the attention of a distant party, and which apprises him that a message is desired to be forwarded through his receiving apparatus. We are all familiar with this signalling apparatus in the bell of our telephone substation equipment. Similar and frequently much more complex signalling apparatus is required in connection with the proper operation of switching mechanisms in order to permit those responsible

for them to perform their functions expeditiously and with that degree of reliability which is a prime requisite to good and satisfactory service to the originator and receiver of the messages.

Because all forms of electrical communication involve the transmission of electrical impulses the efficiency and general characteristics of the transmitting channels are of the utmost importance. This is true irrespective of whether they are material things like the wires which extend from point to point, or the more immaterial properties of free space as that space is utilized in radio transmission. This importance resides not only in the efficiency and fidelity with which any given set of impulses is transmitted from one point on the earth's surface to another, but also in the insurance against extraneous electrical impulses entering the transmission channel in a way to degrade or mask the impulses delivered to the receiving apparatus for translation into a non-electrical form. We have all had innumerable illustrations of the importance of this latter requirement in connection with the use of our telephones or of our household radio receiving sets. In the case of the former we have had perfectly satisfactory communication interfered with by extraneous electrical impulses, such as those resulting from inductive interference with power circuits or nearby thunderstorms producing highly objectionable noises, while in the latter, particularly in the summertime, so-called static disturbances have frequently rendered our receiving sets entirely useless or have been so objectionable as to cause us to abandon their use temporarily.

Telephony, involving as it does the requirement of a faithful translation and transmission of highly complex wave forms over a wide range of frequencies, imposes by far the most severe requirements on both terminal apparatus and transmitting media of any of the more generally utilized forms of electrical communication.

While the translating and transmission requirements of high

quality program material for entertainment purposes are somewhat more exacting than those normally involved in commercial telephony, they are not different in kind since this service is merely an extension of telephonic translation and transmission.

When we come to the lesser used field of picture transmission and to the still highly experimental field of television, we encounter requirements which are decidedly more exacting. In the case of picture transmission, freedom from extraneous electrical disturbances and absolute uniformity of transmitting efficiency of the channel during the period of transmission are of the utmost importance, since the record at the receiving end is a permanent affair on which every deviation from perfection is recorded.

Television, if it ever comes to have a substantial place in the field of electrical communication, will impose requirements of character and stability on the transmitting channels which are quite outside the range required for ordinary telephony and telegraphy. This is so both because of the enormously wide band of frequencies on which it will be necessary to transmit and also because of the fact that the eye will perceive and be annoyed by the objectionable results of extraneous electrical impulses.

As telephony involves more delicate actuating forces in the transmitting and receiving terminal apparatus than does telegraphy, and as it involves requirements of a much wider and more complex transmission band than telegraphy, it is quite safe to say that the successful solution of a telephone problem carries with it in general essentially the basic solution of telegraph problems under corresponding conditions. Not only are telegraph problems, particularly as they relate to the transmission channels, inherently simpler than telephone problems, because of the much narrower bond of frequencies involved and the far greater simplicity in number and form of the impulses required, but they are simpler also because of the fact

that at the receiving end considerable variations in form of the wave impulses can be tolerated without disastrous results. This is due to the fact that telegraph receiving apparatus can be made to rectify variations of wave form provided only that the number and arrangement of impulses in the wave train are the same as at the transmitting end. This flexibility is substantially absent in the design of telephone receiving apparatus where the ultimate translator from electrical to non-electrical impulses can only follow these impulses and so produce sound waves which closely approximate in form the electrical waves delivered to the receiving apparatus. If these latter waves are badly distorted as compared with those at the sending end, so also will the sound waves be badly distorted. There comes thus a point where the value of the system as a means of intelligence communication is destroyed because the received signals are no longer understandable even though they may possess large amounts of energy.

In all forms of electrical communication the final standard by which judgment is rendered is the degree of perfection of operation after the desired connection has been established between transmitting and receiving apparatus. Deviations from perfection in this respect are involved either in our inability to produce a perfect plant, through lack of understanding, or other reasons, some of which I will mention in a moment. While this is the final standard of judgment, speed and accuracy in establishing the desired connection is of only slightly less importance, particularly in the case of telephony, where final judgment resides in the patrons of the service, whose only interest is in the usefulness of that service to them and in the price which they must pay for the facility.

In all forms of commercial electrical communication—and practically all electrical communication outside that of the military services is in this category—cost is an essential element. There are numerous instances in every branch of electrical communication where deviations from the best that it is

physically possible to produce are imposed by this element of cost. Only in very rare instances in the field of commercial communication can a general service be justified for any length of time without regard to the item of expense. This is not necessarily so in connection with electrical communications for the military services, where the criterion is different and where in many instances almost any price can be paid for the accomplishment of a desired result.

I have taken the time to give you this rather long preamble concerning the more important fundamental requirements of electrical communication so that you might better understand why we devote so much time, energy and capital to an intensive program of physical research. Every item which I have mentioned, and an innumerable list of secondary items which I have not mentioned, are known to be susceptible of improvement in performance, reliability, simplicity or cost, provided only that we have a sufficient knowledge of the things of nature and sufficient ingenuity to apply them. So great are the number of directions in which improvement can be anticipated, that the limit of our activity is imposed by our ability to obtain the right kind of men and the amount of money which we can afford to devote out of our current resources in any given year to the securing of results which must of necessity find their application and profit in a period ahead.

Electrical communication, resulting as it has from the scientific discoveries of the past one hundred years, is in its main aspects devoid of that help which numerous other industries derive from the accumulated experience of many centuries of human activity. Since it is the practical application of relatively recent research in the fields of physics and chemistry, it is both natural and inevitable that to a very large extent it has had to look to the colleges and universities which produced the new knowledge, for a very large proportion of the men who have contributed to its advancement.

Quite early in the development of telephony it became ap-

parent that progress could best be made by a different and more profound adoption of the scientific method of attack than was ordinarily employed in the so-called experimental laboratory. In many directions, even, it was clear that no progress at all could be anticipated unless the problems were attacked with the type of men and the methods which have proved to be so powerful in extracting new knowledge from nature. The embryo of what is now a vast scientific research and development organism thus came into being.

Growth was at first slow and somewhat halting. This was due partly to ignorance of how best to proceed, partly to that conservatism which seems inherent in our human activities, and largely to sheer inability to obtain the right type of trained men. The graduate schools of thirty-odd years ago, which were the sole potential source of the type of men required, were not organized to train men for a life in industry, nor did they then attract many men who were temperamentally qualified for such a life. In the years which have elapsed, these obstacles have disappeared with a rapidity which is akin to the progress of an autocatalytic reaction, until at the present day, expansion of the research laboratory is limited principally by the element of current cost, although as mentioned earlier, the question of suitable human material is still a factor.

Initially the problems of the research and development laboratory were largely those connected with the removal of obstacles immediately blocking development. In the main they were solved by application of existing scientific knowledge, and little or no attempt was made to produce new scientific knowledge or to break out new methods of electrical communication in remote fields. As time went on three things became increasingly obvious: first, that there were innumerable problems in the existing art which, while not presenting serious obstacles at the moment, could nevertheless be attacked advantageously by the new organization; second, that in many directions it was not sufficient to depend entirely on the store

of existing scientific knowledge; and third, that there were possible developments in the field of electrical communication which offered alluring prospects but for which as yet there was no need. This latter development evolved rapidly as the size of the research group increased and its members became more conversant with the needs of the communication business and the possibilities it offered for useful expansion.

Coincident with the developments just mentioned there was a growing appreciation of the fact that in every direction in which improvement could be anticipated, the best results were obtained when there was the most complete and certain knowledge of each constituent element which in any manner entered as a factor.

Thus, gradually, under the influence of these several forces, our present great industrial research laboratory has evolved. As you are aware, it now comprises literally thousands of highly trained men and women, many of whom are recognized throughout the world as leading authorities in their several fields of major activity. While many of these men and women are essentially specialists in some particular field, the Laboratories organization is not simply an aggregation of specialists; rather, it is an association together of a large number of broadly trained intellectually competent individuals capable of attacking effectively a wide variety of problems. This organization of the personnel of the Laboratories is of the utmost value, not only in the orderly expansion of electrical communication but likewise in the maintenance of that stability and continuity of association without which it would be both expensive and unsatisfactory. No better proof of the flexibility and soundness of the arrangement is required than that found in the history of the organization during the past three or four years, which have seen such stupendous changes in the general economic structure. Three or four years ago, at the height of the boom period, a major part of the activity of the Laboratories was concerned with the rapid solution of problems of

immediate and pressing necessity. Many of the more fundamental problems concerned with future development had either to be deferred or attacked in a moderate way only. As conditions changed and the pressure of immediate urgency relaxed, there was no material contraction in the size of the research and development force. There was, rather, a smooth transfer of emphasis to attack on those fundamental problems which we have reason to believe are involved with the future developments of electrical communication. No such result could have been obtained in a less flexible organization or in one whose personnel was essentially that of a group of narrowly trained specialists.

To an observant outsider entering the research and development laboratories for the first time the impression is largely that of a great university laboratory. The type of men and women is the same, many of the problems under way are akin, and the general atmosphere of the human relationships is not dissimilar. In two major respects only is there a marked difference; first, in the obvious presence of the fact that time is an essential element, and second, the almost equally obvious fact that practical results and ultimate cost are controlling factors.

Now a brief picture of the kinds of problems with which we deal, of where these problems arise and of how we utilize the results of our work.

In the last analysis nothing which comes out of the research and development organization is of value or is undertaken unless it is a useful physical thing; a useful part of a useful physical thing, or a useful arrangement of useful things. Mainly these have to do with improvements in the field of electrical communication, although latterly they have been concerned to some extent with arts just beyond the border of electrical communication narrowly defined. Such applications have resulted from the obvious by-product advantages of knowledge

acquired in the quest for a broader, better and cheaper electrical communication.

These being the criteria by which the activities and results of the research and development organization are measured, and since useful physical things can be no better than the poorest of the elements of which they are composed, it follows that a very large part of our activity is concerned with the ultimate properties of matter in so far as those properties are a factor in our problems and in developing the various useful ways in which materials and simple structures can be assembled together in the complex things which go to make up a communication system. In a word, our problem in one of its larger aspects is to provide the fabricator and operator—using these words in a broad sense—with the best possible building material. Thus we have come to be vitally concerned not only with the ultimate properties of matter in its most elementary forms but also with the properties of matter in its grosser and more complex aggregates, and in the controls which must be exercised and maintained if the desired properties are to be assured when large quantity production is undertaken. Metals, both primary and in the form of alloys, the methods of their manufacture, the effects of heat treatment and manipulating operations, and their stability under a wide variety of conditions, all come within the scope of our interest. So also do practically all of the non-metallic materials likely to have any place in the field of electrical communication.

Since magnetic materials have a very important place in electrical communication, as they do in all other fields of electro-technology, their non-material characteristics are of very great interest to us. So also, during the last decade or so, have come to be the properties of metals, their alloys or compounds, as producers of electrons.

In quite a different field we are vastly interested in the so-called laws which govern the propogation of electro-magnetic impulses through space, whether it be free space or that por-

tion of space which is limited by the guiding effect of wires. Likewise, we are interested in the means and methods by which electrical impulses may be created, controlled and manipulated to the end that they may be used as vehicles for the transmission, to a distance, of intelligence. The quest for knowledge and power of control in this field has led us not only far in the physical laboratory but far also into the realm of abstruse mathematics, which is a terra incognita to the great mass of human beings.

With the passage of time the extension of our knowledge and the increasing stringency of requirements brought about by growth in size and complexity of the communication network, we have found it necessary and profitable to carry our research investigations ever deeper into the realm of the physically obscure or unknown on an increasing number of our problems. Today, as Dr. Fletcher and the others may have told you, we are vitally interested in an accurate knowledge of many things which a few years ago would have appeared to be quite foreign to the specific interest of the developer of electrical communication. For example, we are now vitally interested in questions of anatomy and physiology in so far as they pertain to the production and character of speech or the sense of hearing. Likewise, we are interested in knowing all that the most powerful ultraviolet microscope can tell us about the internal structure of matter, and in the life and propagation of molds and other organisms of decay. To an extent also we are interested in the life and habits of insects, such as termites which attack and destroy non-metallic substances, and those rarer but more remarkable insects which in some regions attack certain metallic structures.

Having given you a skeleton picture of some of the things in which we are interested and the reasons for that interest, let me conclude by outlining briefly the origin of our problems, the methods by which we attack them, and the uses to which we put our results.

The sources of the problems which present themselves to the research and development organization are four in number.

First, there are the problems which arise out of the day by day commercial operations in the communication field. These may be due to any one of a variety of causes—demand for new types of service which cannot be furnished through the use of existing instrumentalities—high maintenance costs—prospective economies through simplified apparatus or systems, etc.

Second, there are the problems of a more general and less immediate nature which arise out of the general understanding of communication needs possessed by the development and research organization itself. In the main these are problems which, when solved, inaugurate more or less sweeping changes in existing methods or instrumentalities, or open up hitherto undeveloped fields of electrical communication.

Third, there are the problems which arise in connection with the manufacture of physical things. They may come about because of difficulties that have been experienced, because of a belief that through research new materials or new methods of fabrication may result in more efficient or cheaper and less bulky and less complicated apparatus, or they may be initiated by the development of entirely new methods or new materials in entirely different fields but which our general knowledge leads us to believe can be utilized in electrical communication.

Finally, there are the problems which arise directly out of the current discoveries in and expansion of the fundamental sciences. Some of these discoveries and some of this expansion are the result of our own work, but for the most part they are the work of scientists throughout the world which, when published, adds to the store of common knowledge and presents to the trained industrial research man the possibility of useful application. More even than is the case with problems in the second category, the results which follow the solutions originating in this new knowledge are destined to find their

field of application in the communication systems of the future and are most likely to involve radical general changes from the then existing methods. In this respect they are frequently the problems in which the greatest return for the least expenditure of time and money is to be found.

When a problem, from whatever source it emanates, is proposed, the first step is to formulate it as simply, exactly and concisely as possible. The next step is to scrutinize it from every angle with a view to determining not only the probability of a successful solution, but likewise the probable time and cost of obtaining the solution and the benefits likely to be derived from its successful completion. If and when it is decided to proceed with the work, the next step is to break the problem down into its component uncertainties, to formulate for each of these the most rigid possible set of requirements, and then to submit the several parts to the scrutiny and attack of those who are most competent to handle them.

During the course of this frontal attack general supervision is exercised to insure, first, that progress toward an answer is at a reasonably uniform rate everywhere; and second, that the results obtained in one portion of the field are not of such a character as to alter the entire picture as it was originally conceived. Where this latter occurs it results in a realignment of requirements and a new frontal attack from the new point of departure.

In time the separate results are brought together and the complete solution begins to emerge. Finally, when a satisfactory answer seems at hand, the composite solution is subjected to those overall tests which are to determine its ultimate utility.

In general, so far as the Bell System is concerned, it can be said that no piece of apparatus, no equipment and no method of operation is ever released for commercial use until it has been subjected to all of the tests in the laboratory which the

human ingenuity of the research and development organization can devise. In a word, no part of the research and development program contemplates the acquisition of knowledge through experimentation on the customer or with the facilities provided to give him service where this can be avoided. Since from its very nature much of electrical communication, particularly in the field of telephony, must be judged finally by its reaction on human beings, and since the more complex structures can only be tested finally through extensive usage, it is not always possible to avoid entirely a certain amount of experimentation with the patrons of the service. Where this kind of thing cannot be avoided it is, however, always limited as much as possible and confined to carefully supervised trial installations under conditions which previous study has determined as most typical of the general results to be anticipated in universal usage.

As all of the research and development work in the field of telephony, and much of that in telegraphy, is directed to the simple objective of a better, cheaper and more extensively usable system of electrical communication, the multitude of problems which present themselves in never-ending succession, all resolve themselves in the last analysis into the problem of finding better, cheaper and simpler ways of making new things to take the place of existing things, to the problem of making new things for new uses, of broadening, cheapening and making more reliable the band frequency characteristics of the transmission channels, and finally, of making improvements in methods which will take us farther toward the goal of a substantially instantaneous service of universal applicability at a cost which will place this service, in all its parts, within the reach of the largest possible number of people who may desire to avail themselves of it.

A complete list of all the things of utility in the communication field which have resulted from our fundamental research work is entirely too long to incorporate in a lecture of this

kind. A few examples of the results which have had the widest general applicability must therefore suffice to illustrate the things which could not have been obtained except through the work of the Research Department.

In the field of transmission we have substantially obliterated distance as a limiting factor. Further, where wire lines are involved—and they of course constitute all except a fraction of a per cent of telephone communication channels—the size of the conductors has been so reduced that in many cases the limits to a further reduction are imposed not by any electrical requirement but merely by the grosser mechanical requirements. In a word, where it was necessary a couple of decades ago to employ copper wires approximating in diameter the diameter of a lead pencil to insure satisfactory telephone communication over even a moderately long distance, it is now quite feasible to give a better grade of transmission over many times that distance using wires which are not larger than the lead in a lead pencil. Moreover, as a result of fundamental research it is now possible to incorporate in the limited diameter of a 2½" pipe as many as 1800 non-interfering telephone channels, where only a few years ago but a fraction of this number could be obtained, and where at a slightly earlier period none whatever.

It was not so many years ago that each pair of wires supplied for a telephone circuit was limited in its capacity to a single message at a given time. Now, as a result of our fundamental work it is physically possible to transmit a multitude of non-interfering telephone messages, or non-interfering combinations of telephone and telegraph messages over each pair of wires. The question of how and the extent to which this is done are now purely matters of relative economy. In all of this the fundamental developments underlying the distortionless amplifier and the production of highly magnetic alloy materials, both the products of fundamental research, have played an important part.

All of the recent improvements in radio telephony have of course flowed directly from fundamental research work and could have been obtained in no other way.

It is not only in the field of transmission, however, that startling changes have resulted from applying the results of a vast fundamental research. The whole of modern machine switching is predicated on items which have been obtained in the fundamental research laboratory. Probably no other structure thus far created by man comes so near to simulating the operation of an intelligent human being as does the modern machine switching apparatus which is now so commonly used. Save only for the element of articulate speech, the machinery in a modern telephone exchange performs all of the functions originally performed by the telephone operator, and many others besides. Even in the matter of articulate speech, fundamental research has devised machinery by which intelligence originally transmitted by the finger actuated dial used in originating calls is translated into the spoken word in order to convey instructions to a human being—the operator.

In the course of so great and extensive an undertaking as that which is carried on in the Bell System research and development organization, and one in which the satisfactory solution of problems in the field of electrical communication requires such a detailed and intensive study of elementary things, it is inevitable that unsuspected and unsought for by-product results will accrue. Some of these by-product results have been outlined to you by Mr. Otterson and the others who have preceded me. When such by-product values develop they frequently present serious problems in the determination of the disposition which should be made of them. Being things of value, they cannot be abandoned entirely, nor can they in many instances be disposed of in their initial stages. Many of them require specific additional research and development to render them commercially available. In some cases therefore the research and development organization has

carried these by-product values a distance along the course of their development into things of utility. Oddly enough, almost without exception, when this has been done, the further work has resulted in secondary by-products which have had a field of application in electrical communication.

In closing I can only say that the conduct of fundamental research work in the communication field and the utilization of the results from such work are controlled through a combination of the best that fundamental science and scientific training can afford, mixed with the best commercial guidance which we have been able to bring to bear on the matter. Our research and development organization is a truly scientific body, but one in which the results of science are designed to be things of utility to fit into the orderly progress of electrical communication and must be produced with due regard to cost.

FRANK B. JEWETT

Social Aspects of Communication Development

A lecture delivered at the Lowell Institute, Boston, Massachusetts, on January 26, 1932

THE gentlemen who have preceded me in this series of lectures have explained to you some of the methods and results of telephone research. This work has laid the foundations of the talking moving picture industry, prepared the way for television, advanced the method of aiding the deaf to hear, produced an artificial larynx and contributed to the advancement of knowledge of electricity, metallurgy, pure mathematics and in many other ways, but these things are incident to the main purpose to which this research is devoted.

That main purpose is to improve electrical communications, particularly the transmission of the human voice. Specifically it is to enable you to be connected by telephone more rapidly and easily to any one of an ever increasing number of people and when you are so connected to have your conversation clearer and more free from imperfections, errors and delays. It is the desire of these scientists to create as nearly as possible a condition in which you can talk to anyone anywhere in the world with the same satisfaction and with the same effect as if you were talking to some one immediately in front of you. To do that the telephone operation must be so good that you use it as naturally as you use your own vocal cords and it must reach anywhere that you desire it to reach.

Towards this ambitious goal telephone research has made tremendous progress in its half century of effort and it has ever widening possibilities ahead for it is one of the fascinations of the effort to add to human knowledge that each advance in-

stead of tending to reduce the possibilities that remain, seems to increase them.

In the charter granted to the American Telephone and Telegraph Company some nine years after Dr. Bell invented the telephone, the following vision of the future was recorded:

"And it is further declared and certified that the general route of the lines of this association, in addition to those hereinbefore described or designated, will connect one or more points in each and every city, town or place in the State of New York with one or more points in each and every other city, town or place in said State, and in each and every other of the United States, and in Canada and Mexico, and each and every of said cities, towns and places is to be connected with each and every other city, town or place in said States and Countries, and also by cable and other appropriate means with the rest of the known world as may hereafter become necessary or desirable in conducting the business of this association."

That romantic idea was written into the charter at a time when in actual practise there was very little intercommunication between points any distance apart, no telephone communication beyond 250 miles and, of course, none at all overseas.

Yet, although they had no definite knowledge of how their prophecy was to be fulfilled, their faith in the future was largely justified because at present about 92 per cent of the thirty-five million telephones in the world can be reached through any telephone in this country.

The vision that lies ahead is not, therefore, one of possible interconnection with other telephones in the world. In fifty years that prophecy has been largely fulfilled. The vision of the future is one of making telephone connections anywhere and everywhere so convenient and easy that its effect upon humanity will not be gauged by the possibility of people talking anywhere, but by the degree with which that possibility is used.

Some years ago, Dr. Wallace Buttrick, then the head of the General Education Board, said in a discussion of educational

problems, that most graduates of Harvard College were illiterate.

A Harvard man present challenged that statement.

"Dr. Buttrick," he said, "do you mean that in your opinion most of the graduates of Harvard College can not read and write?"

"Oh, no," replied the jovial doctor, "I don't mean that they can't. I mean that they don't."

The difference between the possibility and actuality is likewise an important distinction in the use of the telephone. Technically, the telephone system can be made to reach the whole world. Practically, the task is to increase our telephone systems as fast and as far as the use the public will make of them justifies. There are several limitations on the use that the public will make of them.

The habits of the sun constitute one of the great limitations on world wide telephony. As it shines on only half the world at a time most of the people on one side of the world are asleep at the time those on the other half want to telephone. I remember when we were putting through the experimental calls to Australia. There were several of us talking, one after the other, on the New York end. We were all answered by one gentleman at the Australian end. Finally, I asked him if there was anybody else in Australia who could talk on the telephone. He said there was, but he reminded me that while we were talking at a convenient time of the afternoon in New York, it was half past five in the morning of the next day in Australia and there were not so many people who liked to get up at that time.

There is also the handicap of language, for while the telephone can translate the numbers you dial into language, it can not translate English into Chinese nor Persian into Spanish.

The question before the communication business is not what can we do technically, but what can we do that the people want and will use? We like to look upon our activities as a benefit to mankind and measure our progress in those terms. What

good does modern communication do to humanity? It is some aspects of that question that I would like to suggest.

Up to the time of the invention of the telegraph, communication was, generally speaking, tied to transportation. A message had to be carried by a man and it could go no faster than he could go. It is true that semaphores, beacons, smoke signals and carrier pigeons were used, but the very limited amount of their use indicates the severe limits of their effectiveness. In spite of them it is still generally true to say that from the beginnings of history until the invention of the steamboat and the locomotive, man, horse, and sail provided the maximum speed of communication. The Romans, the Incas, and Kubla Kahn all had highly organized communication systems, as did the Persians. In one sense these are the ancestors of the modern post office and telegraph and telephone systems. In another sense they are not at all. The runners of the Incas, the Romans and the great Kahn were an essential part of the machinery by which a small ruling class kept large populations in subjection. These communications were largely made up of the military and political information necessary for the conquerors to maintain this rule over the populace.

Modern communication is chiefly useful so that large populations may know themselves by constant intercourse and thereby improve their economic status and their ability to govern themselves. The underlying purpose of the two systems is exactly the opposite. One gave inside news exclusively to the few. The other is to enable every one to have the same news at the same time and to have equal facilities for personal communication. One tended towards exclusive power, the other tends towards equalization of opportunity. Communications are now one of the great agencies of democracy. In their origin they served the opposite purpose. I believe that the change began with an event not directly within the field of communications.

In a civilization like that of the Romans, the written word

was used as a record and to some extent for communication. But the great mass of people being unable to read and write, were restricted to such messages as they could carry themselves or some messenger could remember for them. There was no substantial change in this condition until the invention of the printing press. That gave the written word, the printed word, a new status for the inevitable result of the printing press was that the mass of the people gradually began to learn to read and write.

That was the necessary foundation for the establishment of any general post office system with a modern purpose. While the messenger services conducted by the Persians, Chinese and the Romans might be called a postal service, they were not of the same character as the modern postal service—a cheap, rapid and inviolate delivery of written messages for the masses. That kind of a post office, which is a democratic agency, had to wait for the infusion of learning which was based upon the spread of the printed word. The change in point of view did not come suddenly. Queen Elizabeth prohibited the carriage of letters abroad except by the master of the posts because she wanted to be able to censor all foreign communication. Cromwell applied the same idea to all of England.

The first post office in what is now the United States was organized under a royal patent granted to Thomas Neale in 1691 authorizing him to settle and establish within the chief parts of their Majesties' colonies and plantations in America an office or offices for the receiving and dispatching of letters and packets and to receive same and deliver the same. Post riders were dispatched between Portsmouth, N. H., and Virginia weekly except during the winter, when the trips were made fortnightly.

By the time of the Revolution the immense importance to a self-governing country of a general, regular and inviolate communication system was well recognized and the articles of confederation provided for interstate mails. The Constitution gave Congress very wide powers under which to establish a

comprehensive post office, and on the earnest recommendation of Washington this power was immediately used. The post office was to be one of the main ties that would bind the scattered population together.

In Washington's first annual message in which he strongly urged a comprehensive postal law, his arguments for it were based chiefly upon the fact that a well operated post office would encourage a knowledge of the laws and the proceedings of the government. The sociological value of general popular intercourse by mail was not generally grasped at the time for in the society in which he moved in the new republic, there were few people compared to the present who had occasion to use the mail except on rare occasions.

But the general use of the post office grew very rapidly. Communication by steamboat and rail added to its speed. None the less communication was still tied to transportation. Communication, or at least a part of it, took on a separate existence with the invention of the telegraph.

The work of a surprisingly small number of men of which Benjamin Franklin was one, made up the basis of knowledge of electricity up to the beginnings of the nineteenth century. Many people had worked in electricity but the essential contributions to the development of electrical communications were from a surprisingly small number of sources. The next steps, as is often the case, were made almost simultaneously in two places. Michael Faraday, one of the most distinguished members of the Royal Society in London, and Joseph Henry, a school teacher in a small academy in Albany, each without the knowledge of the other, contributed the scientific knowledge necessary for the invention of the telegraph. Neither was utilitarian minded and neither envisaged a public telegraph system. That came from the brain of a painter, Samuel F. B. Morse. With his application of Henry's and Faraday's science, fast communication began to be released from transportation.

As war dramatizes whatever it touches it is perhaps fair to contrast certain military events before and after the release of communications from transportation.

The United States declared war against Great Britain on June 18, 1812 chiefly on account of British activities under the so-called Orders in Council. In order to smooth the situation the British rescinded these Orders eight days after we declared war, but of course without knowledge of our declaration, just as our Congress had no intimation of their intentions. The peace that concluded this war was signed December 24, 1814, and the largest battle of the war took place at New Orleans on January 8, 1815. In contrast to this—at the end of the world war several million men in arms opposite each other ceased firing on the stroke of eleven.

Andrew Jackson's inaugural message in 1831 took 15 hours to reach New York and that speed was due to the extraordinary enterprise of the Courier and Enquirer. Seventeen years later, in 1848, Philip Hone, a New York merchant, wrote in his diary:

> " The Milwaukee Sentinel contains the following article—a most wonderful illustration of the magical performance of the lightening post, the last miracle of the scientific triumphs of the present age: At nine o'clock yesterday morning we had, by telegraph the news and markets from New York, distant fourteen hundred miles, up to three o'clock of the preceding afternoon. This is, indeed, a startling fact and may well make us pause and wonder at the agency which has brought it about." Hone comments, " I was once nine days on my voyage from New York to Albany."

The effect of the telegraph on the dissemination of news and on the conduct of politics would occur to every one, but I am not sure that the revolution in commerce created by instantaneous news would occur to every one so readily.

The Business Historical Society has given me copies of various New England merchants' letters in the days prior to the telegraph and cable. They are letters of instructions to captains and supercargoes of vessels. They are nearly all vague and indefinite, because the merchant had no idea of what the

prevailing price of his goods would be when they reached Canton, Tabago, Manila, nor what would be the price of the tea, molasses, hemp that the ship was to bring back. And if the captain of the ship sold his cargo well in Manila and bought hemp at what was a good price in Boston when he left, he could only hope that it would likewise be a good price when he got back. There is one letter from Canton from a captain of a Boston ship in which he says "The advices from England by the July mail do not warrant the prices previously demanded here for black teas." The letter was written on October 3d. He was bargaining on the basis of information from Britain three months old and the price he finally paid for it would not be known to William Appleton and Company in Boston, for whom he was acting, for several months more. Moreover, while he waited to bargain he had to hold his ship and crew idle, and while he was bargaining he had no idea what was happening to the price of tea in Boston and London.

The commercial situation between Baltimore, Philadelphia and New York on the one hand, and Cincinnati, St. Louis, New Orleans and Milwaukee on the other, would be only relatively better than that between Boston and Canton.

It was not surprising, therefore, that the printing of the New York markets of Monday in Milwaukee on Tuesday morning was an event of importance.

The old trading without knowledge involved tremendous risks. Risk is expensive and the public ultimately pays the expense. We are disposed to criticize our present distribution methods. Perhaps we should do better than we do with the facilities for instantaneous reports from all markets. But what is possible now would seem the millennium of safety to the William Appleton and Companies of the thirties.

There is a story rather commonly accepted to the effect that the Rothschild fortune was greatly augmented by the purchase of securities in London the day after the battle of Waterloo was fought, when the Rothschilds had the news of the victory by

special messenger and no one else knew the facts. Whether this case be true or not it is typical of the results of an undemocratic state of communications, in which the men with fastest messengers could be in the position of prophets. And so long as communication was based on a horse race or a boat race or a train race—so long as it was tied to transportation—this condition continued.

For example, let me read you a part of a letter from Jefferson describing what happened when Hamilton touched the dead corpse of credit so that it sprang upon its feet. As you remember his touch consisted of having the United States agree to pay at par the obligations of the Continental Congress and obligations of the different states.

Mr. Jefferson after describing the measures wrote: "This being known sooner within doors than without, and especially to those in distant parts of the Union, the base scramble began. Couriers and relay-horses by land and swift-sailing pilot boats by sea, were flying in all directions. Active partners and agents were associated and employed in every state, town and country neighborhood, and this paper was bought up at five shillings and often at two shillings in the pound, before the holder knew that Congress had already provided for its redemption at par."

Had a modern communication system been in existence then the government could probably have put its credit on its feet without a scandal that created a prejudice impairing that credit from its restoration until Jackson destroyed the United States bank.

Prior to the advent of electrical communications there was a far greater opportunity for men to bet on events the outcome of which they knew with men who did not know the facts, and to call this practise trade and commerce.

By the time the telegraph was established the written word had attained both speed and mass production. Letters formed the main point of communication between people and letters

were delivered as fast as man could deliver them with the aid of steam on shore and at sea. But the telegraph supplemented this with much greater speed for individual messages and also for new items so that the dissemination of news over the country through the papers was, for the first time, practically simultaneous.

The invention of printing, the spread of education and the invention of the telegraph had all greatly increased the value of the written word in communication. The spoken word had remained exactly as it had been in the city states of Greece. Man had still to find his neighbor before he could talk to him and he could reach no more of an audience than the strength of his voice would allow.

But the study of the science of electricity did not stop there. Moreover, scientists began to find out a great deal about sound waves and light waves as well as electricity. I hope no one will think me an iconoclast if I say that philosophy would have been more pleased with the logical sequence of communication development if at this time, or even earlier, the third type of communication waves had been discovered, that is, electrical or radio waves. Sound waves, light waves and radio waves are ideally suited for general communication purposes because they move in every direction from their point of origin, but sound waves and light waves can not travel great distances over the surfaces of the earth. Radio or electrical waves on the other hand, do travel great distances in spite of the curvature of the earth. If man had discovered radio waves when the Lord intended him to do so, then in all probability we would have had radio telegraphy before Morse discovered wire telegraphy. And wire telegraphy would have been recognized to be what it is—an improvement upon radio telegraphy for the purposes of taking a message from one particular point to another. In the same manner had electric waves been understood when they should have been, when Alexander Graham Bell had discovered how to transmit speech waves, that is, sound waves, to electric

waves, he would have had at his command, first, radio broadcasting and after that the next logical discovery would have been the method of carrying speech from one particular point to another along wires. The use of private circuits to carry speech from one person to a particular desired listener would have been acclaimed as a most notable advance. And as this could be done with none of the extraneous noises of interference which characterizes much of radio reception, it would have added to the marvel. The world would then have assessed the discovery of wire telephony even higher than they did in 1876, for the world would have understood very much more what Bell had achieved.

Electric waves predicted mathematically by Maxwell in 1865, experimentally produced in 1888 by Hertz and adapted to commercial uses by Marconi in 1895, provide the most direct use of electricity in communication. The wire telegraph and the wire telephone are additional steps to that fundamental discovery. The discovery of the wire telegraph and the wire telephone came first. When radio came along the public to some degree looked upon it, not as a predecessor as it properly was, but as a successor of wire communication, and failed to realize that these things are of a complementary and not a competitive character.

Radio is ideally suited for broadcasting with all that the word broadcasting signifies. Radio waves serve admirably in a one way communication system for the dissemination of news, music and entertainment. They serve also for two way communication over those routes where the cost of wires in relation to the amount of traffic renders wires or cables for the present, commercially unjustifiable. Radio also is the only method of reaching ships at sea and aircraft in flight. But for the millions and millions of two way telephone conversations and telegraph messages between particular points, the wire systems are by far the most practical media.

Since the time of this discovery in 1876 the spoken word has

regained in a large measure the position it had in the time of the Greeks and Romans, that is, it is the most common form of intercourse between individuals at a distance as well as when they are close together. The increase in speed which came to the written word first through the post office and then by the telegraph has been applied to the spoken word in even greater degree. Mankind is now equipped with both facilities. A man may write to another anywhere in this country and have the written message promptly delivered. He can take up his telephone and talk almost instantaneously to anyone anywhere in this country. If he and his correspondent have a great deal of business, he can write on the teletypewriter in his office and have his correspondent's teletypewriter on the other end of the wire type the message in unison with his own. He can even, within the last few months, have his teletypewriter connected by a switchboard to different subscribers just as his telephone is connected through a switchboard. He can send messages by cable or radio and he can talk by a combination of wire and radio telephony to any one of 92 per cent of the telephones that exist in the world. In other words, we have the instruments for talking or writing instantaneously to anyone anywhere at any time. And the wires carry news to newspapers and the wire networks for broadcasting enable us to get a message from any point in this country to practically everybody in it simultaneously.

What use do we make of these facilities?

The post office which does the part of written communications still handled by transportation, delivers about sixteen billion letters a year, that is, sixteen billion personal messages, as they are first class mail. The telegraph companies deliver one-fifth of a billion messages or one to every seventy-five letters. There are about twenty-seven billion telephone messages, or about five telephone messages to every three letters. The voice has become the main method of communication between those who are separated, which is entirely natural, as talk is

the main method of communication between those who are together. The social consequences which have eliminated distance as a barrier to the human voice have been as revolutionary as the elimination of time from the transmission of the written word and is quite as much taken for granted.

These communication facilities are the natural tools of a democracy. To what extent they have increased democracy it is idle to speculate, but they have come with it and are a natural part of it. Knowledge is power and the control of knowledge is power. The control of communications and, therefore, of the knowledge of specific events, is a very important element in power. If that is in the hands of a few autocracy is almost inevitable. If it is in the hands of the many, democracy is possible. And generally speaking, the wide use of public communication is a symptom of democracy. Those countries which are democratic in their social, political and economic structure use the tools of communications to the greatest extent. I said particularly that where communications are available to the many democracy was possible. It is not inevitable for the tools of mankind can not automatically make mankind over. Providing China with railroads and telephones will not make a stable democratic government. To do that the Chinese will have to acquire the knowledge and habits and desires for that kind of government.

There are those who are critical of our modern age and seem to believe that at the present time the tools control the man rather than the man controlling the tools. But I think they say this chiefly because it is easier to blame the machines than it is the people. Our machines do what we tell them to—they add to our powers but they do not direct our purposes.

The ability to have personal contact with other people is the principal source of both pleasure and power for the individual. That increase in power is easily thought of in connection with business. It is true that modern business could not go on in its present form without modern communication. It could not

go on without the telephone. Without the telephone you could not have a skyscraper, for you could not get enough elevators in a skyscraper to carry the messenger boys that would be necessary to deliver the notes and telegrams. The telephone has in this way allowed us to congregate where we wish to congregate. It has also facilitated living in the suburbs and in the country so that it has allowed us to disperse where we have wanted to disperse. Instantaneous communication has had an essential part in increasing the average income in this country for it is an essential part of the improved machine tools and methods of production and distribution.

Modern business is based in varying degrees upon the communication system in which the spoken as well as the written word can be instantaneously projected to any necessary point. It is true as the last two or three years have made painfully apparent, that all these modern tools put together have not eliminated the vicissitudes of human affairs. They are not automatic and as I said before they do not control mankind. They give man the power to do many things he could not do before and to do other things with greater facility, but they do not control the degree nor the direction in which he uses that power.

But equally important with the business use of the telephone is its social use. It has added safety, comfort, convenience, and a wider range of friendly human contacts to the people's lives. How do you measure the value of hearing a baby's laugh over the telephone? What good is it that you can get a friend for lunch on the spur of occasion? How valuable is it to be thirty seconds from the fire-house even if the fire-house is half a mile from you?

Before the advent of electrical communication a man was apt to confine his human contacts largely to his immediate neighbors, for the simple reason that he could not easily maintain contacts with any one else. A man's neighbors now are more the people of his choice than those who happen to live next door. This may add to his enjoyment and development.

These things are so common that it is hard for us to realize that, taken in the aggregate, they form an immense addition to human comfort and happiness. In saying that, I know that there is no statistical proof possible that people are happier than they used to be, for happiness is not yet a measurable quality. Yet there is one basis on which to gauge the increase in comfort or happiness arising from rapid communications and that is the ever increasing desire of the people for them.

Of course there is occasionally a reaction against increasing power, for with it goes inevitably an increasing sense of responsibility.

We have had instances in this country of voting to abolish the results of science because they tend to increase the necessity for thought. There are other people who dislike the other aspects of modern science because they too increase both opportunity and responsibility. I have heard of a summer colony in this country that is in this state of mind. The inhabitants hold, with O. Henry, against having their retreat damaged by improvements. Tradition is against the telephone. Yet some years ago a new comer joined this colony and brought a telephone with him. Outwardly respecting the traditions of the place he had the line to his house as well screened by trees as possible and he put the instrument in the upstairs hall so that no visitor would be scandalized at its sight. The tradition against the telephone still remains but the gentleman with the telephone has had to take great care in what costume he emerges from his bedroom for at any time of the day or night there may be a neighbor in the hall telephoning.

Years ago I used to hear people complain of the farmers' wives gossiping on the telephone. Yet that was probably by far the most important function of many a rural line, for to keep a woman from going insane from loneliness is far more important than finding a market where pigs sell a half cent higher a pound. The telephone in its social uses saves people, particularly women, an immense amount of time and drudgery.

What do we do with the time we save? I don't know. Again I can't prove that it is usefully, profitably or spiritually employed. But people think, at any rate, that it adds to the fullness and happiness of their lives to save that time and I think there is an instinct in all of us that cries out for the opportunity to experiment with the high art of living without having the experiment entirely controlled by the time and difficulty of making a living.

Temporarily, now and then, the world and the people in it are too much with us, but we, like our ancestors, are an energetic and sanguine people. We want more command over nature, more tools, more appliances, more power, for we believe in ourselves and enjoy being, in so far as we can manage it, the captain of our souls and the masters of our fate.

To those of us who work in the science, art or business of communication, this is the inspiration for our work. We believe in the urge of mankind towards better things. We believe that in removing the limitations of time and space from the words of man we are giving him the ability to make a more effective civilization. And particularly we believe it is important to increase the influence of his brain by facilitating human intercourse for it is by the origination and spread of ideas that progress is made. They are far more important than any material things.

Electrical communication has been used to revolutionize the methods of commerce, to make the news instantaneously common to all men, to restore the influence of the spoken word in politics, to bind this country together with a constantly changing but ever present web of words, and recently by the trans-Atlantic telephone, to make a great change in the conduct of international relations. These and many others are the proof that electrical communication has given man immensely increased power. Whether it is used to make more money or better men, to increase comfort and happiness or the opposite, to make a better or worse civilization, to promote peace or war

depends not on the facilities at his disposal but on man's desires. But being optimists both as to the public's intentions and abilities in the long run, we get a satisfaction from adding to those powers by spreading the word of man instantaneously to the four corners of the country and almost anywhere else he wishes.

ARTHUR W. PAGE

Another Evidence of Evolution

IN the making of America's telephone system, the rule of the survival of the fittest has been applied without discrimination to the equipment which makes service possible. This is the inflexible law of progress. In the process of evolution, there is no room for sentiment. And yet—there is always something a little heart-stirring when a veteran piece of equipment, a time-honored tool of the telephone service, is laid aside to make way for something which can perform a particular function more efficiently.

So it is with a circuit layout chart which hangs on the wall in a room on the third floor of 15 Dey Street, New York City. On it are shown all the open wire telephone and private wire telegraph circuits maintained and operated by the Long Lines Department of the American Telephone and Telegraph Company. It is, in effect, a diagramatic map of the United States, from coast to coast. It is forty feet long and seven and a half feet high—and it is to be discarded because, of all possible reasons, it is too small.

When the Long Lines Department moves up to its new quarters at 24 Walker Street, this month, the open-wire circuit layout chart will be replaced by another which will be fifty feet long and ten feet high—another illustration of progress through evolution. The chart has been in service since 1922. Now, ten years is a long time, as the lives of charts are measured, so that this particular chart is really a grizzled veteran, facing retirement with many scars to show for long years of service. If it were possible for inanimate objects to become articulate, it might look back upon the events of a decade of telephone history and remark, with a hero of old, "All of these things I have seen, and a part of them I was."

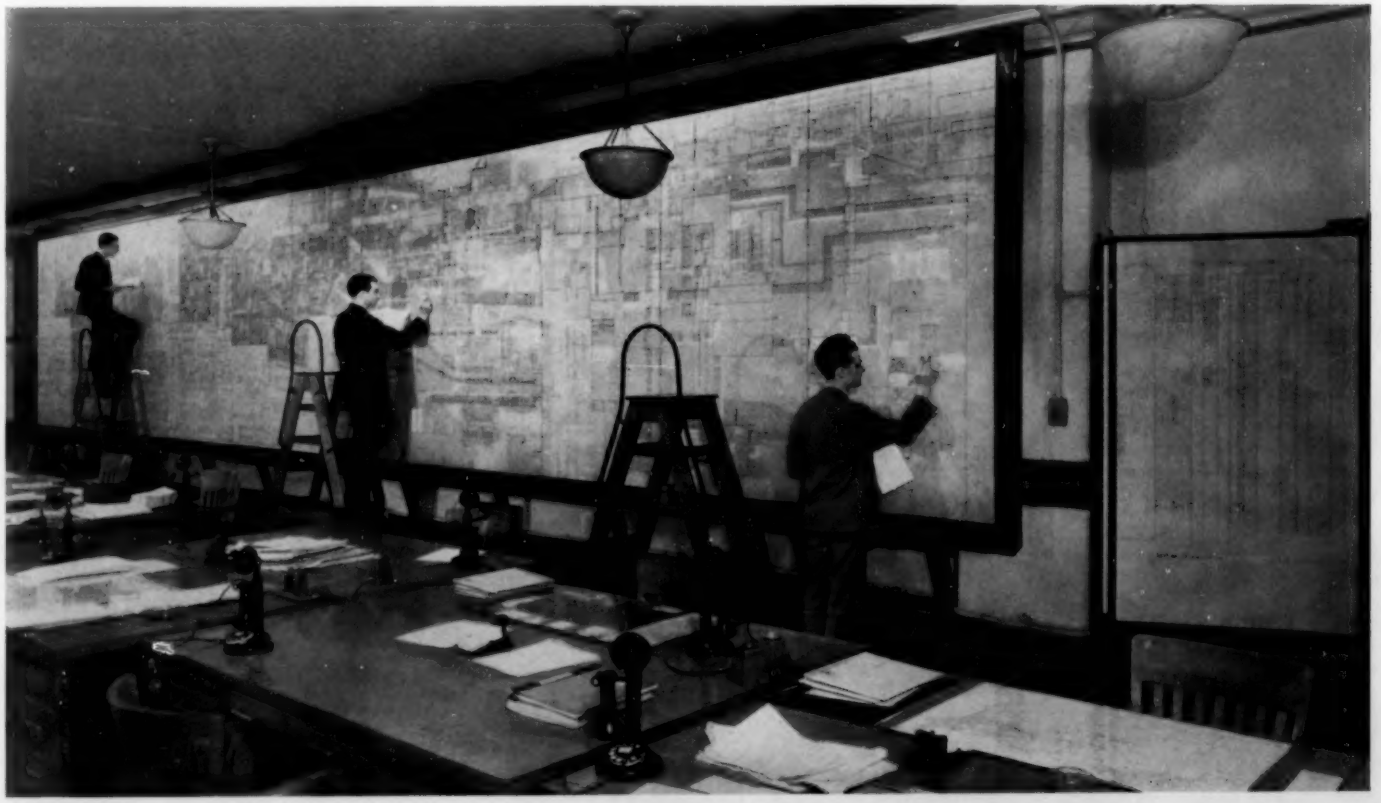
From year to year, almost from day to day, its notations

have reflected ten years of growth of telephone facilities—possibly the most remarkable ten years in the history of communication. It has borne mute but eloquent testimony to the extension of the Bell System's lines to meet a nation's needs. It tells, of course, only a part of the story of this telephone growth, for the record of cable circuit layouts is kept on a separate set of charts—216 of them, with a total chart space of 3456 square feet. But it tells, by inference, something of the story of cable development as well as that which has had to do with open wires. There are great white spots here and there—where erasures have been made to indicate that open-wire facilities have been dismantled and replaced by cable. A study of these erasures will show that they have moved from the right hand side of the chart toward the left, silently telling the story of how the Bell System has pushed its network of long distance cables far into the Middle West.

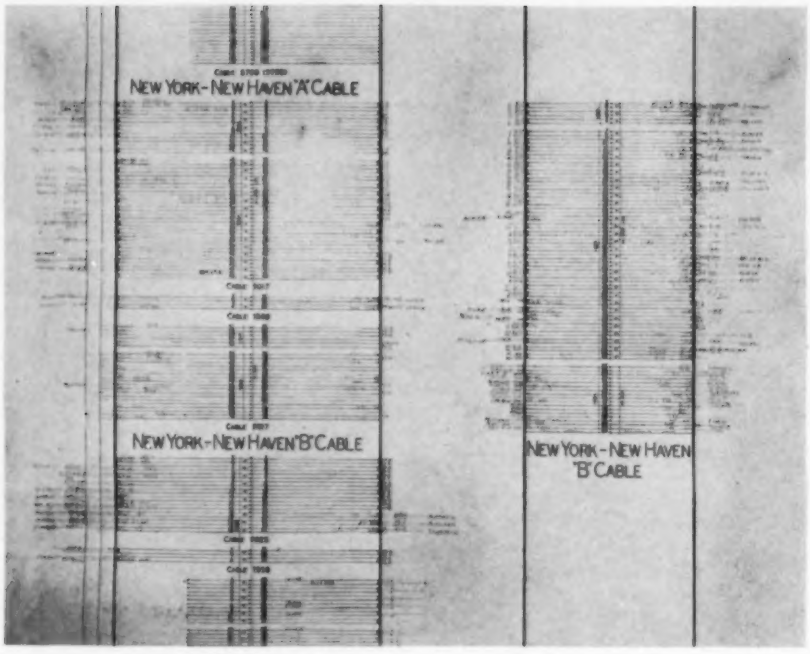
The circuit layout charts tell more of a story than that which relates to the development of telephone service. It is not difficult to read between their lines another story—the current history of the American people: their economic and social habits; their political battles; the ebb and flow of their business; the sporting events that absorb their interest; their carefree migrations to places where they find rest and recreation; their periodic outbursts of unashamed sentiment.

The Circuit Layout Group

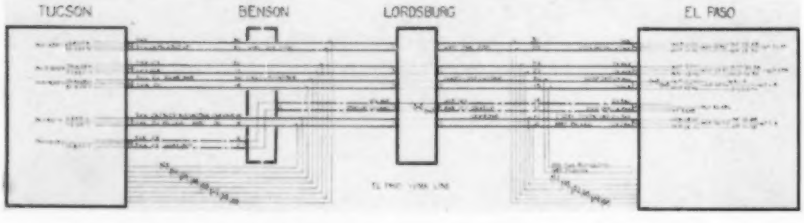
Maintenance of these records is one of the functions—but only one—of a most important but little known branch of the Long Lines Department which is designated as the Circuit Layout Group. It may be well to review briefly the activities of this organization and to see how important a part it plays in enabling the greater organization which has come to be known as the Bell System to perform its functions. As its name implies, this group is responsible for engineering and



OPEN WIRE CIRCUIT LAYOUT CHART AT NEW YORK HEADQUARTERS OF LONG LINES DEPARTMENT, A. T. & T. CO. At right is shown one of the cable circuit layout charts.



PART OF ONE OF THE 216 CHARTS ON WHICH ARE RECORDED DATA REGARDING THE LONG LINES CABLE CIRCUIT LAYOUT.



A TYPICAL PORTION OF THE BIG OPEN WIRE CIRCUIT CHART SEEN AT CLOSE RANGE.

ordering into service a layout of telephone and telegraph circuits that will provide efficient and economical service. It should be understood that it has jurisdiction only over the circuits maintained and operated by the Long Lines Department of the American Telephone and Telegraph Company for the purpose of linking the Associated Companies of the Bell System. Each Associated Company has its own circuit layouts for local and toll telephone service, private line telephone and telegraph service, etc. Within its own territory each Associated Company consequently has its own organization for engineering these layouts and ordering them into service.

The Circuit Layout Group here discussed is located at Long Lines headquarters in New York and is made up of representatives of the Long Lines General Plant, General Traffic and Engineering Departments. The group is composed of one general Circuit Order Committee and nine section Circuit Order Committees. These section committees correspond to the nine sections into which the United States has been divided for long distance telephone traffic purposes. Each section committee, as well as the general committee, has a Plant, Traffic and Engineering Department representative.

These sections are: 1. New England States. 2. New York State. 3. New York-Pittsburgh. 4. Pennsylvania west of Pittsburgh and the State of Ohio. 5. South and west of Chicago and the Mississippi River. 6. Southern States. 7. New York-Washington. 8. Indiana and Michigan. 9. North and west of Chicago and the Mississipi River.

The Circuit Layout Group has nothing to do with the actual planning and construction of new facilities. With the steps involved in the provision of these facilities, from the forecast of the General Commercial Department to the setting of poles by the Plant Department, many readers are more or less familiar.

Let us assume that these steps have been taken and that a particular group of telephone and telegraph circuits is about

to be made available for service. As the work has gone along, its progress has been noted on monthly construction schedules issued by the Division Plant Construction Department. Copies of these schedules have been turned over to the Circuit Order Group and the dates appearing on them are the determining factors which control the issuing of circuit orders.

How Circuit Orders Are Issued

Once a week the Circuit Order Committees meet to review layout work and schedule circuit orders. Based upon reports of the Plant Department as to construction progress and statements of the Traffic Department as to its circuit requirements, circuit orders are tentatively agreed upon, either placing new construction in service or authorizing rearrangements of existing layouts so as to meet the requirements of the existing situation or those of the immediate future. The draft of each proposed circuit order is submitted to each office interested and such changes made as may be necessary. Work on the draft is scheduled so as to have the final copy of the circuit order released to the field from two to four weeks before the "for service" date upon which the facilities will be put into commercial operation.

So much for the routine of issuing circuit orders for newly constructed facilities. In the main, the same routine applies to changes in layout of existing facilities. As soon as a circuit order becomes effective, the essential facts regarding the circuits involved are recorded and the assignments of facilities are noted on the charts. These notations are made in pencil so that changes may be made conveniently when necessary. The gauge and loading of the facilities are shown on the charts and a card index is kept showing the detailed makeup and necessary transmission information of each telephone circuit. A separate card record is kept for telegraph circuits, showing the routing and methods of operation of each circuit.

Extent of Long Lines Facilities

Let us see what maintenance of such a record involves. The Long Lines Department has more than 895,000 conductor miles of open wire and more than 5,161,000 conductor miles of cable in service for telephone and private line telegraph purposes. These are actual, physical circuits. In addition, there are 180,000 circuit miles of open wire phantom circuits; 1,290,000 circuit miles of phantom circuit in cables; 375,000 channel miles of carrier telephone circuits; and 1,018,000 channel miles of carrier telegraph circuits. Telephone and telegraph circuits assigned to these facilities are as follows: telephone message circuits, 6581; private line telephone circuits, 411; private line manual telegraph circuits, 681; and private line teletypewriter circuits, 570. In addition, many more circuits are assigned for program transmission, telephotograph transmission, teletypewriter exchange service, maintenance purposes etc.

It might well be assumed that, after doing all the detailed work required in getting new circuits ordered into service and properly recorded on these layout charts, the easiest thing to do would be to let them alone. And so it obviously would be —but it would not always be the efficient or economical thing to do. There is nothing static about the telephone business. It changes from year to year—almost from day to day, hour to hour and minute to minute—to meet requirements arising from changing conditions. As the service changes—and, indeed, before it is possible for it to change, in many cases—there must be changes in the circuit layouts.

Changing Layouts to Meet New Conditions

It is because the Long Lines circuit layouts must be changed constantly to meet the requirements of new conditions that the charts kept by the Circuit Layout Group so accurately reflect the life of millions of Americans. If one were to run

through the records of a year with a member of the Circuit Layout Group, as the writer did recently, one would find that a series of changes in circuit layouts is made every year to keep pace with the shifting seasonal demands for telephone and private line telegraph facilities arising out of movements of great masses of people to vacation resorts. Atlantic City, for example, must be given a group of additional circuits to take care of its winter peak, which extends from about Lincoln's Birthday through Easter, and still other facilities to meet the demands of its greatly increased mid-summer population.

In early June or thereabouts, circuits must be provided to handle calls of vacationists in the Catskills and the Adirondacks—the New York State summer layout. There is a similar New England summer layout which furnishes extra circuits for the use of those who seek recreation on Cape Cod or the Maine Coast or in the White Mountains. The resorts of northern Michigan must be taken care of, and an extra circuit or two run into the Yellowstone National Park.

Just when the Circuit Layout Group has a chance to catch its breath after its efforts to take care of the summer vacation peak, another makes itself manifest. From the latter part of August through Labor Day, extra circuits must be assigned to Montreal to care for the requirements of Americans who make pilgrimages across the Canadian Border.

Early in December circuit orders for the Florida layout must be in the field, including private line telegraph and telephone circuits as well as extra long distance telephone facilities. It is important that the American business man on vacation be able to keep in touch, not only with his home and his office, but with the activities in Wall Street, and the tapping of teletypewriter keys at various points along the Florida shore helps to provide this necessary communication link. The Florida long distance telephone and private line traffic reaches its peak in February and recedes as the army of vacationists moves northward.

Holiday Traffic Peaks

These traffic peaks are, it will be observed, geographic as well as seasonal. There is another peak which knows no state boundaries, but pervades the whole nation. It has nothing to do with climatic conditions. It is purely a matter of sentiment. It comes with the arrival of Christmas and continues through New Year's Day. During this week Americans forget the fluctuations of their investments for a little and think of friends and relatives far away. From one corner of the continent to the other, long distance telephone calls increase in number by leaps and bounds. For this temporary overload the telephone circuits must be made ready. Circuit orders are issued, erasers are applied to one portion of the layout chart and pencils to another, and spare facilities are made available where experience has shown they will be most needed. When the holidays arrive, every available circuit must be ready for service—because Americans are, after all, a sentimental folk and when they get ready to wish somebody a "Merry Christmas," they do not care to be delayed in acting upon this praiseworthy impulse.

A Record of Political Events

Even the political activities of the American people may be reflected on the notations on the circuit layout charts. Once every four years the United States must go through the process of selecting candidates to run in the forthcoming presidential election. The cities in which the two major parties hold their national conventions must be provided with telephone facilities to take care of the requirements of the delegates and, to an even greater extent, with private line telegraph and teletypewriter circuits to meet the needs of the press. If the convention happens to be held in a city which does not normally have a considerable number of "spare" circuits, the Circuit Order Group is likely to spend many hours of anxious thought

in preparing for the temporary but exceedingly urgent demand for telephone and telegraph facilities.

For similar reasons a presidential inauguration places a heavy tax on circuits into Washington and provision must be made for taking care of this one-day rush of private line telegraph, teletypewriter and long distance telephone traffic. Even after a president has been safely elected and inaugurated, his personal habits may have a marked bearing on the number and the difficulty of the problems which the Circuit Order Group is called upon to solve. If the Chief Executive usually stays in Washington, with short trips to a nearby summer camp, as does Mr. Hoover, the problem is relatively simple. But if he makes a practice of taking long railroad journeys at frequent intervals or spending his summer vacations first in one part of the country and then in another, the charts of the Long Lines Department must record the fact that additional telephone and telegraph circuits have been assigned to points along the presidential itinerary. Not only must there be sufficient telephone and telegraph facilities to keep the official party in touch with Washington, but once again private line telegraph and teletypewriter circuits must be provided for the use of newspapers and press associations. It sometimes becomes of momentous interest to the people of the United States to know whether, on any particular morning, their Chief Executive has fished with worms or with a fly—and whether he has caught anything. There are times, too, when they are vitally concerned in hearing that he has spent a good share of a summer afternoon sitting on one end of a log—with a British Prime Minister sitting on the other. For out of these presidential summer camps there come, over the private line telegraph and teletypewriter wires or by long distance telephone, not only items of news which are essentially trivial, but those which tell of events that may profoundly affect the history of the nation and of the world.

Strawberries and Sporting Events

The Circuit Order Group must have at least a working knowledge of scores and almost of hundreds of activities in which the American people engage or interests which hold their attention. Its members must, for example, know enough about agriculture to predict with measurable certainty when strawberries will begin to ripen on the eastern shore of Maryland. Strawberries are a perishable crop and must be sold and shipped in a hurry, once they begin to turn from green to red. This means urgent long distance calls between farmers and their market representatives, and these, in turn, involve more circuits—or trouble. So a group of additional facilities is set up each year to take care of this situation. Among the members of the Circuit Layout Group it is known as the Strawberry Layout.

Nor can the strategists on this important sector of the Bell System battle-line afford to become so absorbed in statecraft or in strawberries that they forget to study the sporting pages. When the warm days of April come and the bleachers echo to the cheers which greet Babe Ruth's first home run, every Big League city must have extra newspaper and press association private line telegraph and teletypewriter facilities. At World Series time, these demands are still further augmented in the two cities in which the championship is to be decided. There would be trouble, too, if some year the Circuit Layout Group were to forget that there are such things as the Indianapolis Speedway motor races, or the annual gridiron clashes between Harvard and Yale and other traditional rivals, or pugilistic encounters of major importance. Anything that makes news makes demands for communication facilities and consequent changes in telephone and telegraph layouts—if the news is big enough.

It requires but little imagination to see in these Long Lines circuit layout charts—some of them bearing the scars of long

service, as does the big open-wire chart—an important contribution to contemporary Americana. Upon them are reflected the incidents and events which make up America's current history. Here, too, is recorded, in a never-ending succession of pencil lines, erasures, and still other pencil lines, the continuing growth of a great communication service that is playing a vitally important part in helping America to fulfill its destiny.

R. T. BARRETT

Award of the John Fritz Medal to Dr. Michael I. Pupin

Editor's note:

The John Fritz Medal is the honor given jointly by four national engineering societies; the American Society of Civil Engineers, the American Institute of Mining Engineers, the American Society of Mechanical Engineers, and the American Institute of Electrical Engineers. It was established in 1902 in honor of John Fritz, of Bethlehem, Pennsylvania, and is awarded not oftener than once a year for notable scientific or industrial achievement. The Board of Award is formed of sixteen men, four representatives from each of the four Societies.

On January 27, 1932, at a meeting of the American Institute of Electrical Engineers, this medal was presented to Dr. Michael I. Pupin, Professor Emeritus of Electro-Mechanics at Columbia University, New York City, whose loaded telephone line invention more than thirty years ago was an outstanding fundamental contribution to telephone engineering, and who is held in highest esteem as a member of the Bell System family.

At this meeting the address in regard to Dr. Pupin's achievements was made by Mr. Bancroft Gherardi, Vice-President and Chief Engineer of the American Telephone and Telegraph Company. It is printed below in full together with Dr. Pupin's response after the presentation of the medal.

Mr. Gherardi's Address

FIFTY-EIGHT years ago, late in the winter of 1874, a young Serbian landed at Castle Garden. He was without money or property, without friends or influence, and without

knowledge of the language of this country. Many would say that he had nothing; but this would fail to recognize the things which he had. He had good health, character, ambition, a mind eager to find knowledge and to use it, and high ideals.

This evening I have been selected as the spokesman of four great engineering societies whose representatives are gathered here to pay a tribute of esteem and affection to him.

Limitations of time compel silence upon Dr. Pupin's early struggle for an education, and his studies at Columbia, Cambridge (England), and at the University of Berlin; except only this, that no one can read the account which he gives of this period of his life in his wonderful autobiography without being convinced that in the earlier influence of his mother and in the period in which he was getting his education, was laid the foundation upon which rest his many achievements during a long and varied career. From the time of his connection with the staff of Columbia University, the story of his life is a continuous record of contribution to our knowledge and our methods of thought. Of these only a few high spots can be mentioned this evening.

Perhaps because I am a telephone engineer, I am starting by referring to his invention of the loaded telephone line. For a number of years prior to Dr. Pupin's work which led to his inventions and patents on this subject, it was known that the addition of continuously distributed inductance to a telephone circuit would add to the transmission efficiency of the circuit, that is to say, would diminish the losses of the telephone current during its passage through the wires. It had been suggested that similar results should follow from the placing of inductance coils at intervals in the circuit. This had even been tried experimentally without favorable results.

By means of a beautiful mathematical investigation Dr. Pupin established the fact that it was not sufficient to place inductance at intervals in the circuit, but that the inductance

must be designed with reference to the conditions of the circuit and must be uniformly spaced at intervals having a relationship to the shortest waves which it was desired to transmit. He confirmed the results of his mathematical investigations through a brilliant series of laboratory experiments and in addition he designed and demonstrated the advantages of the toroidal type of loading coil; a design which fundamentally has persisted even to the present time, although it dates from over thirty years ago.

Dr. Pupin's patents were acquired by the Bell Telephone System and from that day to this his inventions have played a fundamental part in long distance telephony. The time at which Dr. Pupin made these inventions was most opportune. They came just when telephone engineers were confronted with serious problems in the extension of long distance telephone service over greater and greater distances, and also when, due to the unfavorable effects of non-loaded telephone cables, very serious problems were arising in the planning of long distance lines. These problems were particularly difficult where the numbers of circuits required were so great that overhead open wire constructions presented formidable difficulties, and where the lines had to be brought into large cities.

As part of the mathematical investigation of the loading problem, Dr. Pupin developed a mathematical theory of certain forms of artificial lines or electrical networks. Such artificial lines today have numerous important applications in the communication art.

Dr. Pupin was the original discoverer of the electrically tuned circuit, that is, of the possibility of so proportioning the electrical characteristics of a circuit that it would respond energetically to any pre-determined alternating current frequency. The electrically tuned circuit is used today in every important branch of the electrical art, in telephony, in telegraphy, in power transmission, and last but not least, in radio systems. It was first used by him and then by others in the

analyzing of alternating currents, that is to say, in their separation into the different frequencies of which they were composed.

In a way, Dr. Pupin was unfortunate in the time in which he made this invention. Electrically tuned circuits are used in every radio receiving set. At the time that he made the invention, however, the radio art was practically non-existent and for many years thereafter it was used only for incidental and specialized purposes. Today, however, practically every home contains an electrically tuned circuit in the radio receiving set, but Dr. Pupin's discovery was so far ahead of the development of radio and therefore of the general use of tuned circuits that few realize today that, if this contribution of Dr. Pupin's were to be removed from the radio systems of the present day, they would no longer function.

Immediately upon the discovery of the X-Ray, Dr. Pupin made two important contributions. He was the first to discover the phenomenon of secondary X-Ray radiation, that is, that when X-Rays strike on any matter, that matter becomes itself a source of X-Ray radiation. This fact was not only important in itself, but it contributed to many other scientific advances in X-Ray work. Dr. Pupin did much experimental work in X-Ray photography and he was, I believe, the first in this country to make an X-Ray picture with the aid of a florescent screen. The advantage of this method over those previously used was that it enormously shortened the time necessary for the photographic exposure and made it possible to take X-Ray pictures in many medical and surgical cases where, without a short exposure it would not be practicable to get an effective X-Ray picture.

Dr. Pupin was the first to suggest the use of an electrical rectifier in connection with the receiving of radio signals. While Dr. Pupin's original invention made use of an electrolytic type of rectifier cell, his invention was broad enough to cover the use of any type of rectifier element. Here again Dr.

Pupin was unfortunate in that his invention was so far ahead of the development of the radio art that it was many years after his work was done before there was any extensive opportunity to use practically this contribution.

Dr. Pupin has had an important part in the building up of the scientific and engineering departments of one of our greatest universities—Columbia University. He has not only contributed much in this way, but the graduates of Columbia University who studied under him have in many cases made distinguished records in the fields of science and engineering. Of the many, I shall only mention two—Dr. Robert A. Millikan and Gano Dunn, a Past President of the American Institute of Electrical Engineers. These and many others testify with the greatest enthusiasm to what they owe to Dr. Pupin's teaching and to his inspiration.

During the war, Dr. Pupin had an important part in starting the National Research Council. The purpose of the National Research Council as defined by President Wilson in his executive order with reference to it was: "stimulating research in mathematical, physical, and biological sciences, and in the application of these sciences to engineering, agriculture, medicine, and other useful arts, with the object of increasing knowledge, of strengthening the national defense, and of contributing in other ways to the public welfare." Throughout the period of our participation in the war, Dr. Pupin devoted his abilities and his boundless energy to the vital problem of submarine detection.

No statement of Dr. Pupin's achievements, however brief, could omit the mention of his autobiography, itself a contribution to literature, to science, and to education and a wonderful study in the process of Americanization. From this book many native-born Americans can learn something of the spirit and aims of our country.

Dr. Pupin's honorary degrees, his membership of societies and his presidencies of them, his American and foreign decora-

tions, medals and awards are too numerous to mention, but they testify to the judgment of others as to his personality and his work. In 1921 the American Institute of Electrical Engineers awarded to Dr. Pupin the Edison Medal, the highest honor which that Society could confer. Now three other great engineering societies, Civil, Mechanical and Mining have joined with the Electrical Engineers in awarding to him their great joint honor.

Dr. Pupin, I salute you:

An inventor who has made important contributions to the application of electromagnetism to the uses of man.

A scientist who has added important facts to our knowledge of science and contributed to scientific idealism.

An educator who not only has an enviable record as to those who have studied under him, but who has advanced the cause of education.

A citizen who has contributed much to this country.

An American who is proud of the country of his adoption, and of whom his country is proud.

Dr. Pupin's Response

As I have been sitting here and listening to the kind eulogies which my good friends dedicated to me this evening, I could not help recalling some of the memories of my boyhood days. I saw, as if in a vision, the familiar faces of several peasants of my native village who were my schoolmates over sixty years ago. I imagined them sitting in the front row here and dazzled by the brilliancy of this festive occasion they asked me: "Michael, tell us what saints and angels of heaven guided you on your way from the humble pasturelands of our tiny village to a place of honor in this glorious palace of the American engineers?" I answered: "Ask Mr. Gherardi to give you a Serbian translation of the speech which he dedicated to me this evening; that will answer your question better than I can

answer it." I shall add only this: At every step of my uphill road I found generous encouragements in this blessed land. Above all I must mention here the generous spirit of my Alma Mater, Columbia College. The enjoyment of its scholarships, fellowships and research facilities helped me more than words can tell to make my modest contributions to science and engineering. Without this help I would not be with you this evening. The generous spirit of my Alma Mater was the same as that which prompted the John Fritz Medal Board of Award to confer this high honor upon me. I gratefully accept it, and I shall treasure it as a precious symbol of the generous spirit of this blessed land which always made me feel that life is worth living.

Permit me now to take up another line of thought. I have been informed that you expect me to bring you a message from the age of science in which I lived and toiled as an humble worker. That age is the Power Age and it sends you the following message:

Faraday's discovery of electromagnetic induction, a hundred years ago, is the closing event of a great epoch in the history of physical science and engineering. It is the epoch in which the power age was born.

Watt's invention of the steam engine marks the beginning of this epoch. It suggested to the genius of Carnot the immortal idea embodied in his well known law. This law defines what Carnot called the moving power of fire, that is of heat, a name which today is one of the greatest names in physical science.

Carnot's interpretation of the moving power of heat completed in 1824 the first great step in the evolution of the power age. The second great step was made when in 1820 Oersted discovered the magnetic force of moving electricity and a few years later Faraday discovered the electric force generated by moving magnetism. The law of action of these forces defined the moving power of electricity just as Carnot's law defined

the moving power of heat. We know today that these two moving powers are the fundamental physical powers in the universe, and that their revelation was the greatest achievement ever recorded in the history of engineering sciences. It inaugurated, a hundred years ago, the power age. This age is the parent of our present civilization and the moving powers of heat and of electricity are the propelling powers in the physical evolution of this civilization.

Our civilization very often is called the machine civilization and what I call the power age often is called the age of machines. I don't like these names for the simple reason that machines are the creation of the hands of mortal man. They are transient, but the moving power of heat and the moving power of electricity are eternal; these powers are the immortal elements in the physical structure of our civilization.

Advancement of science during the power age, that is during the last hundred years, revealed that the same fundamental powers which are at work in the evolution of our civilization were also at work in the evolution of organic life ever since life appeared on this terrestrial globe and that they are also the only propelling powers in the evolution of the luminous stars. Radiations from these stars tell us that the moving powers of heat and of electricity are of celestial origin; they were brought to earth on the wings of solar radiation and remained dormant until the genius of Watt, Carnot, Oersted, Faraday, and Henry called them to the service of man. This service is the service of our central star to this tiny terrestrial globe; its mission on this earth recalls the mission of the celestial flame which, according to an ancient legend, the Titan Prometheus snatched from the radiant chariot of the sun god Helios and brought down to earth. The ancients believed that the mission of that celestial flame was to make the life of man similar to the life of the Olympian gods.

We believe that the mission of the moving powers of heat and of electricity, our most precious gifts from our central

star, is to raise the life of man to Olympian heights. But has our civilization, the offspring of the power age, lived up to the lofty aim of this mission?

Two different pictures present themselves to our mental vision when we attempt to answer that question—two entirely different pictures. In one of the pictures I see the triumphant conquest of space by the automobile and the aeronautical art. I see the wonders of power distribution increasing a hundredfold the comforts and the creative power of man, and I am thrilled by the electric waves which sliding over wires or wandering through space convey on their wings speech and melody over continents and oceans to every nook and corner of this terrestrial globe. These are a few of the miracles of our power age by which the moving powers of heat and of electricity have displayed the magic of their celestial origin; they certainly have made the physical side of human life even more glorious than the life of the Olympian gods. This achievement of the power age is its greatest glory.

But the spiritual side of human life, exhibited by another picture, is far from edifying. In this second picture we see desolation on every side in the wake of the most deadly war which the world has ever seen. The world appears here standing on the verge of economic collapse, and yet vast armies and navies are devouring the meager remnants of the wealth of nations while millions of idle workers are starving. The most repulsive figures in this horrible picture are fear and hatred, which, like two ugly demons, are hovering on each side of the boundary lines between neighboring nations.

Banish these demons from the human heart and there will be no need of vast armies and navies to guard our security against hostile neighbors; there will be no hostile neighbors, and wars will become a dying memory only of former barbarous ages. But the celestial servants of our civilization, the moving powers of heat and of electricity, have not banished them.

Science admits that the magic of these two primordial powers cannot unaided purge the soul of man and eliminate the poisons which corrupt its spiritual life. Another moving power is sorely needed which can penetrate more deeply than the moving power of even the infinitely minute electrons into the depths of the human heart. This need was recognized nearly 2,000 years ago when our Saviour revealed the greatest moving power in the spiritual world and commanded us to love the Lord our God, and to love our neighbors as ourselves.

This was a message of the approaching power age in the spiritual world. But this age has not yet arrived; mankind has not yet yielded to the greatest moving power in the spiritual world, and without its aid the moving powers of heat and of electricity cannot contribute their full share to the evolution of the spiritual life of man.

Love of the eternal truth and of their work to reveal this truth for the good of mankind has guided the scientists and engineers to their great triumphs of science. These triumphs of love will persuade the reluctant world that the victorious triumph of the moving power of love which Christ discovered will be the greatest triumph of the power age.

Notes on Recent Occurrences

W. C. FORBES MADE A. T. & T. DIRECTOR

THE directors of the American Telephone and Telegraph Company at their meeting on February 17 accepted the resignation as a director of Jeremiah Smith, Jr. on account of ill health, and elected W. Cameron Forbes to succeed him. Mr. Forbes was formerly a director of the company and resigned to accept the position of Ambassador to Japan last June. He is now retiring from the diplomatic service.

THE ANNUAL MEETING

THE annual meeting of the stockholders of the American Telephone and Telegraph Company was held on Monday, March 29, 1932. The Board of Directors was unanimously re-elected. In all, 382,884 stockholders voted in person or by proxy 11,251,437 shares representing 60.3 per cent of the total stock outstanding.

SHIP–SHORE RATES ON ZONE BASIS

EFFECTIVE April 1, rates for ship-shore telephone conversations with transatlantic liners were placed on a zone basis. When the vessel is more than 500 nautical miles from the American Atlantic coast the charge is $18 for a three minute conversation and $6 for each additional minute. When the ship is 500 or less nautical miles off shore the charge is $9 for a three minute talk and $3 for each additional minute.